ARIZONA DEPARTMENT OF TRANSPORTATION

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COMPARATIVE RISKS OF TRANSPORTING HAZARDOUS MATERIALS ON THE STATE HIGHWAY SYSTEM IN ARIZONA

Final Report

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16. Abstract

The purpose of this research study was to assess the risks associated with the transportation of hazardous materials and hazardous waste on the Arizona state highway system. Another objective of the study was to evaluate the use of a Geographic Information System, GIS, to model the risks to the public.

A statewide GIS model was developed which included over 600 individual segments on the State highway system. Volumes of different categories of hazardous materials were estimated for each segment based on data collected in a previous statewide survey. Truck accident rates were assigned to each segment based on the past accident experience for that segment. Population data from the 1980 census were spatially distributed throughout the state. In addition, the location of emergency response units was also integrated into the model.

For each highway segment, the model estimated the relative probability that a hazardous material incident would occur, the potential population that would be impacted and the emergency response time from the nearest response unit. The results are presented through a series of color maps which depict the relative risk for each category of hazardous material evaluated. The use of the GIS system proved very useful and allowed the integration of highway segment information such as traffic volumes and truck accident rate with spatial data such as population. Emergency response time was easily calculated by the GIS model based on the response unit's proximity to each highway segment. Use of the GIS model also resulted in a more detailed evaluation that has the capability to easily consider additional spatial data such as land use, location of schools and hospitals, weather patterns, etc.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

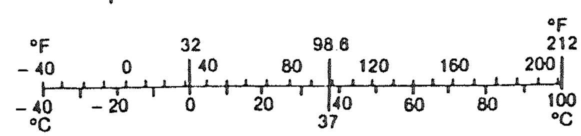
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



(Revised April 1989)

* SI is the symbol for the International System of Measurement

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1.0 INTRODUCTION

The transportation of hazardous materials and wastes has become a routine part of our society. Past studies have shown that one in ten trucks traveling on our highway system is transporting some type of material that is classified as hazardous. This fact presents a challenge to those government officials and professionals in the private sector that are responsible for the safety of the public.

In January of 1986, a study was published which estimated the magnitude, chemical types and hazard class of hazardous material shipments being transported on the Arizona highway system. This study was conducted by the Center for Environmental Studies and School of Public Affairs and Center for Advanced Research in Transportation at Arizona State University in Tempe, Arizona. The study was funded by the Arizona Department of Transportation and the Federal Highway Administration and administered by the Arizona Transportation Research Center.

The 1986 study entitled "Transportation of Hazardous Materials in Arizona" utilized a number of surveys to estimate the type and volume of hazardous materials being transported on over 80 highway segments throughout Arizona. These include: 1) hazardous waste shipment manifest data; 2) two one-week surveys of placarded trucks at Arizona's major ports of entry; 3) an intrastate survey at nine locations; and 4) interviews with distributors of gasoline, acids, and propane.

This follow-on study is designed to utilize the data developed in the 1986 study and evaluate the risks associated with the movement of these hazardous materials. In addition, this study assesses the vulnerability of populations in geographic areas by integrating the emergency response times into the analysis. The evaluation of the risks associated with the transportation of radioactive materials was not within the scope of this analysis.

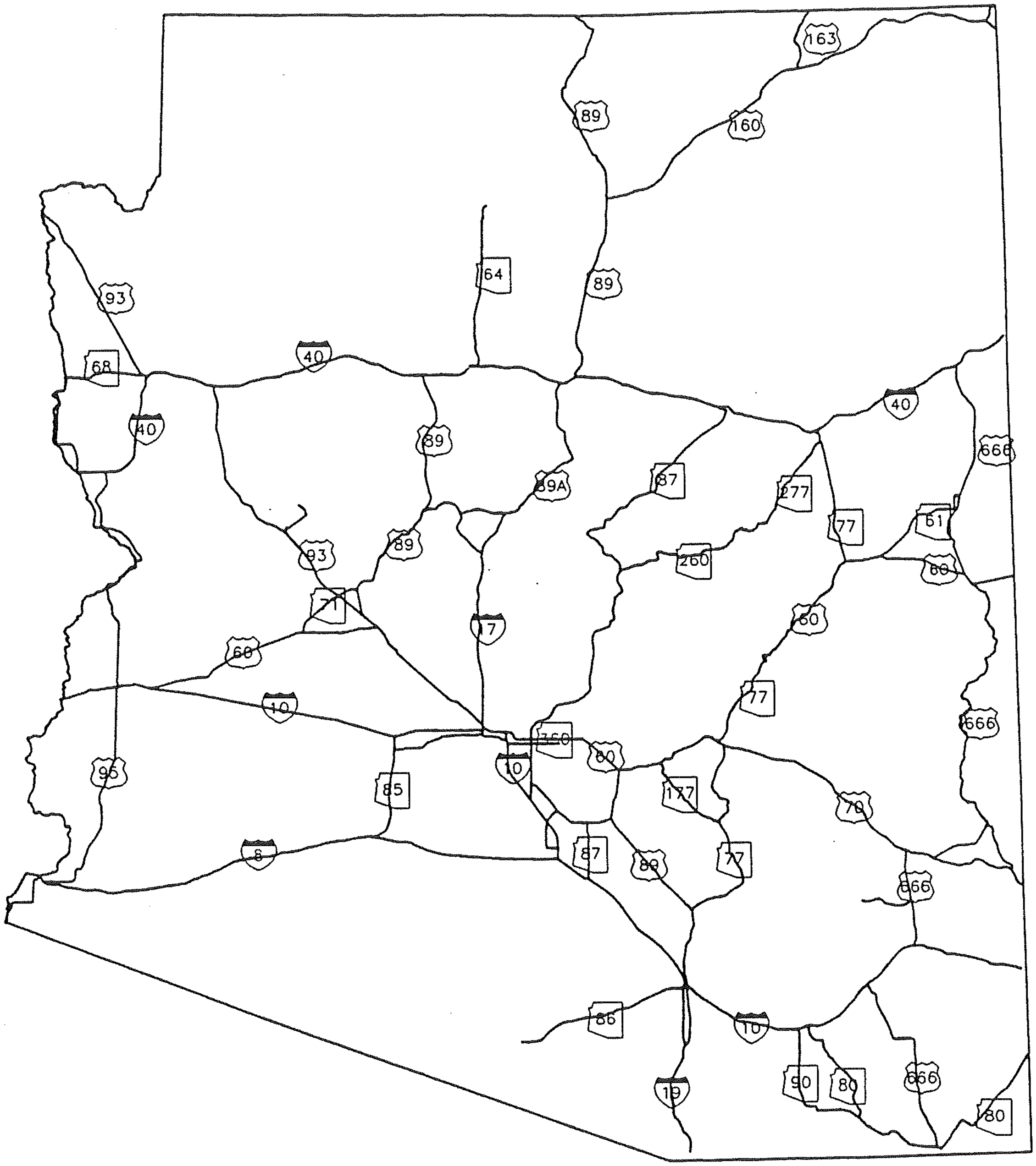
This study was conducted using a geographic information system which is a new approach to risk analysis. Use of the geographic information system provides for a more detailed evaluation of how the transportation system interacts with a wide variety of demographic factors, such as population and land use. Additionally, a geographic information system easily allows consideration of specific sites such as locations of emergency response units, hospitals and schools.

This report is organized into three major categories: 1) the original data; 2) the hazard, risk and vulnerability analysis; and 3) programmatic implications and recommendations. For the purpose of this study, the term hazardous materials will include hazardous wastes.

2.0 STATE HIGHWAY NETWORK

The highway network that was used for this study included the federally aided system of state highways. This system is presented in Figure 2.1 A detailed system map is also provided which identifies each segment designation. The numerical designations of the segments were taken from the original designations in the 1986 hazardous material study. The original 80 segments are identified as the first two digits of a three-digit number. The last digit represents a more detailed breakdown of each segment.

The original data did not encompass the complete federally aided state highway system. Therefore, additional segments were added until the complete system was represented. For numerous segments, hazardous material volume data were not available.



State Highway Network Included
In The Study

Figure 2.1
ATRC/Dames & Moore

3.0 1986 SURVEY DATA

The 1986 survey data for the volumes of hazardous materials and hazardous waste form the basis of the risk assessment. These data were obtained from a study conducted by the Center for Environmental Studies and the Center for Advanced Research and Transportation at Arizona State University. Data on the estimated volumes of hazardous waste were taken from an analysis of hazardous waste manifest for the year 1984. The estimated volumes of hazardous materials transported on the highway system in Arizona were developed from two week-long surveys of inbound trucks at Arizona ports of entry, an internal survey of trucks traveling within the state of Arizona and a telephone survey of transporters of hazardous materials within Arizona.

These data were provided to Dames & Moore on a series of 5¼-inch floppy disks. The following discussion addresses how these data were utilized in the risk analysis.

3.1 HAZARDOUS MATERIAL TRANSPORT

The estimates of the volumes of hazardous materials and the routes they are shipped over were developed through the use of a number of different surveys. Two surveys were conducted at Arizona port of entry stations. These week-long surveys were conducted in March and July of 1984. This survey was designed to estimate the number of incoming and drive-through trips. The estimated number and amounts of hazardous materials entering Arizona at selected ports of entry are shown in Table 3.1.

<u>Table 3.1</u>

TOTAL NUMBER OF ANNUAL SHIPMENTS AND TRUCKLOADS BY PORT OF ENTRY

Port of Entry	Shipments	Truckloads	Tons	Gallons	Total Equivalent Tons
Ehrenberg	46,800	43,368	176,532	149,000,000	799,571
Sanders	99.580	47,840	239,255	117,000,000	730,524
Topock	6,136	5,772	40,437	17,900,000	115,407
Yuma	11,856	11,024	20,740	76,200,000	340,080
San Simon	17,368	11,856	124,225	71,800,000	425,148

In addition to the interstate trips, a 14-day survey was conducted on various routes throughout the state to assess the number and amount of hazardous materials being transported internally. The number of responses to this survey was relatively small and therefore the information obtained was not considered statistically adequate. However, the survey did indicate that the primary types of hazardous materials being transported within the state were gasoline, propane, and acids.

Additional research was conducted to assess the extent of intrastate transportation of these three materials. Interviews with transportation companies and shippers were conducted. In addition, data available on gasoline usage by county was also evaluated. Estimates of the total annual volume of propane, gasoline, and acids were developed for selected routes throughout Arizona.

The estimated volumes of hazardous materials by hazard class were developed and presented in the written report entitled Transportation of Hazardous Materials in Arizona dated January 1986. However, the electronic data provided on the 5¼-inch floppy disks did not contain these annualized estimates. Rather these data only contained the results of the March port of entry survey and hazardous waste manifests. Efforts to obtain more detailed electronic data and backup information used to develop the estimates from the principal researchers was unsuccessful. Therefore, Dames & Moore utilized the data presented in the written report to conduct the risk analysis. These data were obtained from the various figures and tables in the written report which provided generalized information regarding the volumes of hazardous materials being transported by hazard type by route.

The data presented in the figures of the 1986 report are broken into three levels with each level representing a range of shipments, see Appendix A. For example, the flammable category, Figure 39, identified a lower range of 1 to 11,000 shipments, a mid range of 11,001 to 22,000 shipments, and a high range of 22,001 to 33,000 shipments. Since more detailed data were not available, Dames & Moore utilized the mean of each of these three categories for assigning traffic to individual routes for the risk analysis.

Our interpretation of these data are presented in Figures 3.1 through 3.5. The volumes of hazardous materials by route are presented in three categories: 0-25th percentile, 26th-75th percentile, and 76th-100th percentile.

3.2 HAZARDOUS WASTE TRANSPORT

The database provided to Dames & Moore identified shipments of hazardous waste by hazard class and also identified the route and individual segments of a route over which the hazardous waste was transported. The study estimated that 2,933 shipments of hazardous waste were made in 1984. These shipments were transported in 2,521 truck loads, which indicates that a number of shipments were mixed waste where multiple hazardous wastes were transported in one trip. The 1986 study also broke down the hazardous waste by the following classes:

Hazard Class	Definition
Corrosive	Any liquid or solid that causes destruction of human skin tissue or a liquid that has a severe corrosion rate on steel.
Flammable liquid	Any liquid having a flash point less than 100°F with the following exceptions: (i) A flammable liquid with a vapor pressure greater than 40 psia at 100°F; (ii) Any mixture having one component or more with a flash point of 100°F or higher that makes up at least 99 percent of the total volume of the mixture; and (iii) A water-alcohol solution containing 24 percent or less alcohol by volume if the remainder of the solution does not meet the definition of a hazardous material contained in this subchapter.
Solid	Any solid material, other than an explosive, which is liable to cause fires through friction, absorption of moisture, spontaneous chemical changes, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently as to create a serious transportation hazard.
Poison A	Extremely Dangerous Poisons - Poisonous gases or liquids of such nature that a very small amount of the gas, or vapor of the liquid, mixed with air is dangerous to life.
Poison B	Less Dangerous Poisons - Substances, liquids, or solids (including pastes and semi-solid), other than Class A or Irritating materials, which are know to be so toxic to man as to afford a hazard to health during transportation; or which in the absence of adequate data on human toxicity, are presumed to be toxic to man.
Combustible	Any liquid with a flash point from 100°F except any mixture having one component or more with a flash point at 200°F or higher, that makes up at least 99 percent of the total volume of the mixture.
Oxidizer	A substance such as chlorate, permanganate, inorganic peroxide, nitrocarbo nitrate, or a nitrate, that yields oxygen readily to simulate the combustion of organic matter.
Organic	Any organic compound containing the bivalent -0-0 structure and which may be considered a derivative of hydrogen peroxide where one or more of the hydrogen atoms have been replaced by organic radicals must be classified as an organic peroxide.

ORM-A	A material which has an anesthetic, irritating, noxious, toxic, or other similar property and which can cause extreme annoyance or discomfort to passengers and crew in the event of leakage during transportation.
ORM-B	A material (including a solid when wet with water) capable of causing significant damage to a transport vehicle or vessel from leakage during transportation. Materials meeting one or both of the following criteria are ORM-B materials: (i) A liquid substance that has a corrosion rate exceeding 0.250 inch per year (IPY) on aluminum (nonclad 7075-T6) at a test temperature of 130°F.
ORM-C	A material which has other inherent characteristics not described as an ORM-A or ORM-B but which make it unsuitable for shipment, unless properly identified and prepared for transportation.
ORM-D/E	A material such as a consumer commodity which, though otherwise subject to the regulations presents a limited hazard during transportation due to its form, quantity and packaging.
Source:	Transportation of Hazardous Materials in Arizona, Volume 1: Comprehensive Study Approach, Analyses and Findings; 1986.

The 1986 study evaluated all hazardous waste manifests for the year 1984. These data are presented in Table 3.2.

Table 3.2

DISTRIBUTION OF SHIPMENTS OF HAZARDOUS WASTE BY HAZARD CLASS AND VOLUME 1984

Hazard Class	Number of Shipments	Percent of Total	Lbs.	Gallons	Total Weight in Ton[1]	Percent of Total
Flammable	1,009	34.4	3,749,834	784,014	5,158	26.7
Corrosive	434	14.8	1,364,334	706,458	3,641	18.8
Poison	67	2.3	174,498	16,398	156	0.8
Combustible	40	1.4	83,180	15,458	106	0.5
Oxidizer	35	1.2	20,024	11,132	57	0.2
Organic	1	--	0	1	--	--
ORM-A	325	11.1	427,268	128,532	752	4.0
ORM-B	4	0.1	0	12,532	52	.3
ORM-C	15	0.5	130,990	996	70	.4
ORM-E	1,003	34.2	12,764,983	707,088	9,344	48.3
Total	2,933	100	18,715,111	2,382,577	19,336	100.0

[1] A unit conversion factor of 8.377 lbs/gal. was used.

Source: The Transportation of Hazardous Materials in Arizona, Volume I, Comprehensive Study Approach, Analysis and Findings.

As can be seen, the largest number of shipments was in the flammable and ORM-E categories which accounted for 34.4 percent and 34.2 percent of the total shipments of hazardous waste, respectively. The next highest class was corrosives which accounted for less than 15 percent of all shipments.

The volume of hazardous wastes being transported is small compared to the amount and number of trips of hazardous materials. Therefore, for the purpose of this analysis, only hazardous materials were used. The origin and destination information on the manifest provided insight into the routes over which these materials were transported. This information is presented in Appendix A.

3.3 MATERIALS WHICH POSE THE GREATEST THREAT TO THE PUBLIC

State emergency response personnel were interviewed to identify materials that they believed posed the greatest threat to the public from their transportation in commerce by motor carriers. These rankings are presented below by hazardous class:

Ranking	Hazard Class	Specific Product
1	Flammable liquid	Gasoline
2	Corrosive	Sulfuric acid
3	Flammable gas	Propane
4	Combustibles	General
5	Poisons	General
6	Explosives	General
7	Oxidizers	General
8	Nonflammable gas	General

The above ranking of threat to the public from the transportation of specific products/categories is amazingly in line with the frequency and quantity of products/categories being transported (see Table 3.1). The variances in categories ranked five through eight compared to the frequency and quantity of materials in transportation, is minor and much less than expected in this subjective ranking process.

The 1984 surveys (January 1986 report) identified the following materials as the most frequently transported into/through Arizona. The "predominant" hazard class is added to assist in correlating these data with that provided elsewhere in this section.

Product	ID#	Predominant Hazard Class
Gasoline	1203	Flammable liquid
Paint related	1263	Flammable liquid
Resin	1866	Flammable liquid
Adhesive	1133	Flammable liquid
Propane	1979	Flammable gas
Sulfuric acid	1830	Corrosive
Cleaning compound	1760	Corrosive

Note: "Predominant" is used with hazard class to indicate that not all material in the categories listed fall within the specific class shown, i.e., some adhesives are in the combustible class and some cleaning compounds are in the flammable/combustible classes.

There are several factors influencing the level of threat to the public resulting from the transportation of hazardous materials. These factors include: (1) the specific material involved; (2) the frequency at which it is transported; (3) the average load size (volume); (4) point of origin and destination of individual shipments; and (5) population density along the transport route.

The top three specific materials identified by the emergency response community and supported by the data from the 1984 study as posing the greatest threat to the public are discussed below.

Flammable Liquid (gasoline) - The points of origin for gasoline shipments in Arizona are diverse. There are specific areas served exclusively from a given point of origin; however, the following assumes that all extraneous factors are equal and that the point of origin for shipments serving specific areas include:

1. Tank Farm, Phoenix, Arizona - serving central Arizona.
2. Tank Farm, Tucson, Arizona - serving southeastern Arizona.
3. Points in northwestern New Mexico - serving northeastern Arizona.
4. Points in southeastern Nevada - serving northwestern Arizona.
5. Points in southeastern California - serving southwestern Arizona.
6. Points in southern Utah - serving north-central Arizona.

The public threat from the transportation of hazardous materials is greatest at/near the point of origin or port of entry and diminishes significantly with distance (route dispersion based on destination).

Figure 3.1 presents the relative volume of shipments of explosives. Based on these data the following routes from each point of origin are listed in descending order of concern for further study:

1. From the tank farm in Phoenix - The Phoenix metropolitan area for both intra-area/intrastate movement of gasoline is of major concern. As discussed earlier, as distances increase from the point of origin, the threat is diminished. However, the length and frequency of transport in some arterial routes out of (originating in) the metro area should receive special attention. They include I-10 west to S.R. 85, I-10 south (east) to S.R. 387, I-17 north to Flagstaff and S.R. 89 from Cordes Junction to Prescott.

2. From the tank farm in Tucson - The Tucson metropolitan area for both intra-area and interstate movement of gasoline is of considerable concern. Specific intrastate concerns include I-10 east to Benson, I-19 south, S.R. 86 west and S.R. 89 north.

3. All other routes in Arizona are weighted almost equally with minor exceptions. In this case, areas of increased concern include I-40 from Sanders POE to Holbrook, from Topok POE to S.R. 95, and I-10 from Yuma POE to and including all of the Yuma area.

<u>Corrosives</u> - The 1984 study of the movement of acids by motor carrier suggests that a much more comprehensive study of the movement of sulfuric acid (corrosive of principal concern) is needed. The report recognized forthcoming mine closures and other operational changes that would cause "substantial" shift in the shipment patterns of sulfuric acid. When such changes were to occur is not evident and/or if they have or to what degree they have occurred is unknown.

With the limitations indicated above, specific routes of concern are: (1) all intrastate routes identified in Table 29 of the 1986 report (1984 study); and (2) all routes connecting Arizona mining operations, particularly in southeastern Arizona.

<u>Flammable Gas</u> (propane) - The 1986 report acknowledges a lack of data specificity regarding intrastate origin-destination movements of this product. This is considered a significant shortfall in that all areas of the state are vulnerable to the movement of this product

and it is the primary energy source for those out of reach of the natural gas pipelines. The entire intrastate distribution system for propane is a major concern and an in-depth study is needed.

As one might expect, the movement of propane during the winter months is estimated to be 3-4 times that occurring during the summer months. This increased vulnerability period is further estimated to be 7-8 months in duration (September - April). For this reason, the March data on which the 1984 study is based is representative of the annual winter season flow of propane and valid to that extent for the purpose of this study.

ANNUALIZED SURVEY
- **HIGH QUARTILE**
- **MID QUARTILES**
- LOWER QUARTILE
- NO DATA

Figure 3.1

EXPLOSIVE

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

ANNUALIZED SURVEY

HIGH QUARTILE
MID QUARTILES
LOWER QUARTILE
NO DATA

Figure 3.2

CORROSIVE

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

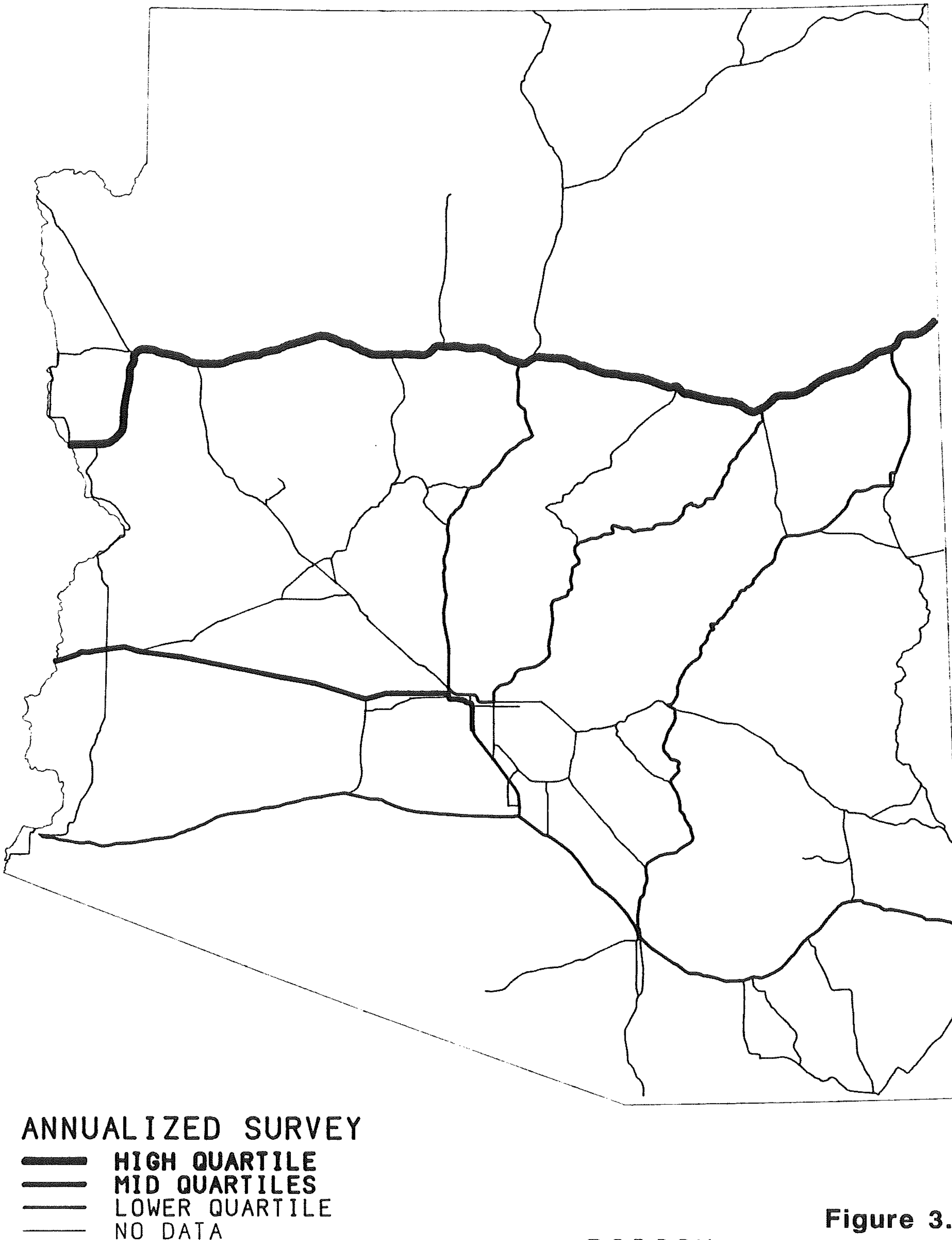


Figure 3.3

POISON

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

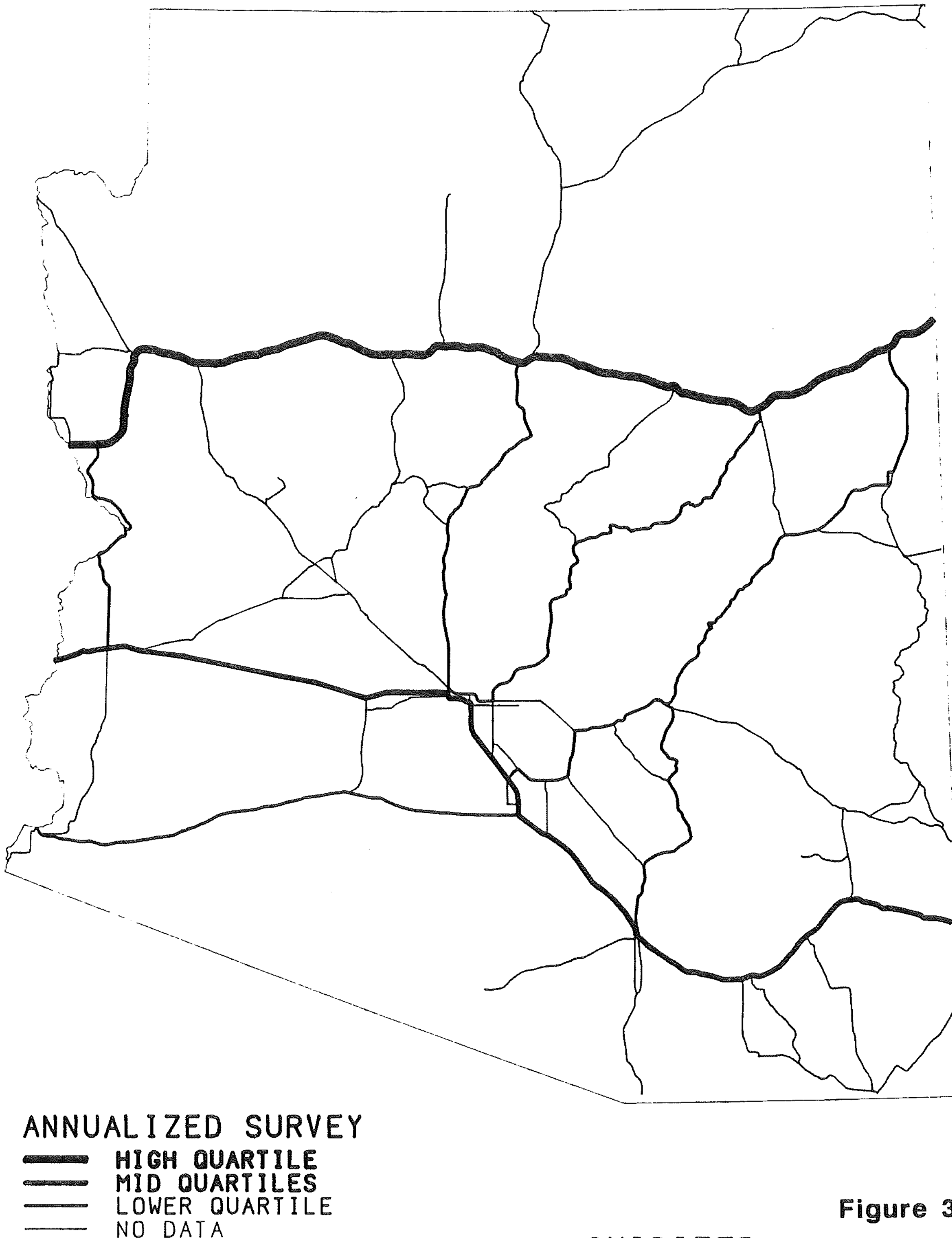
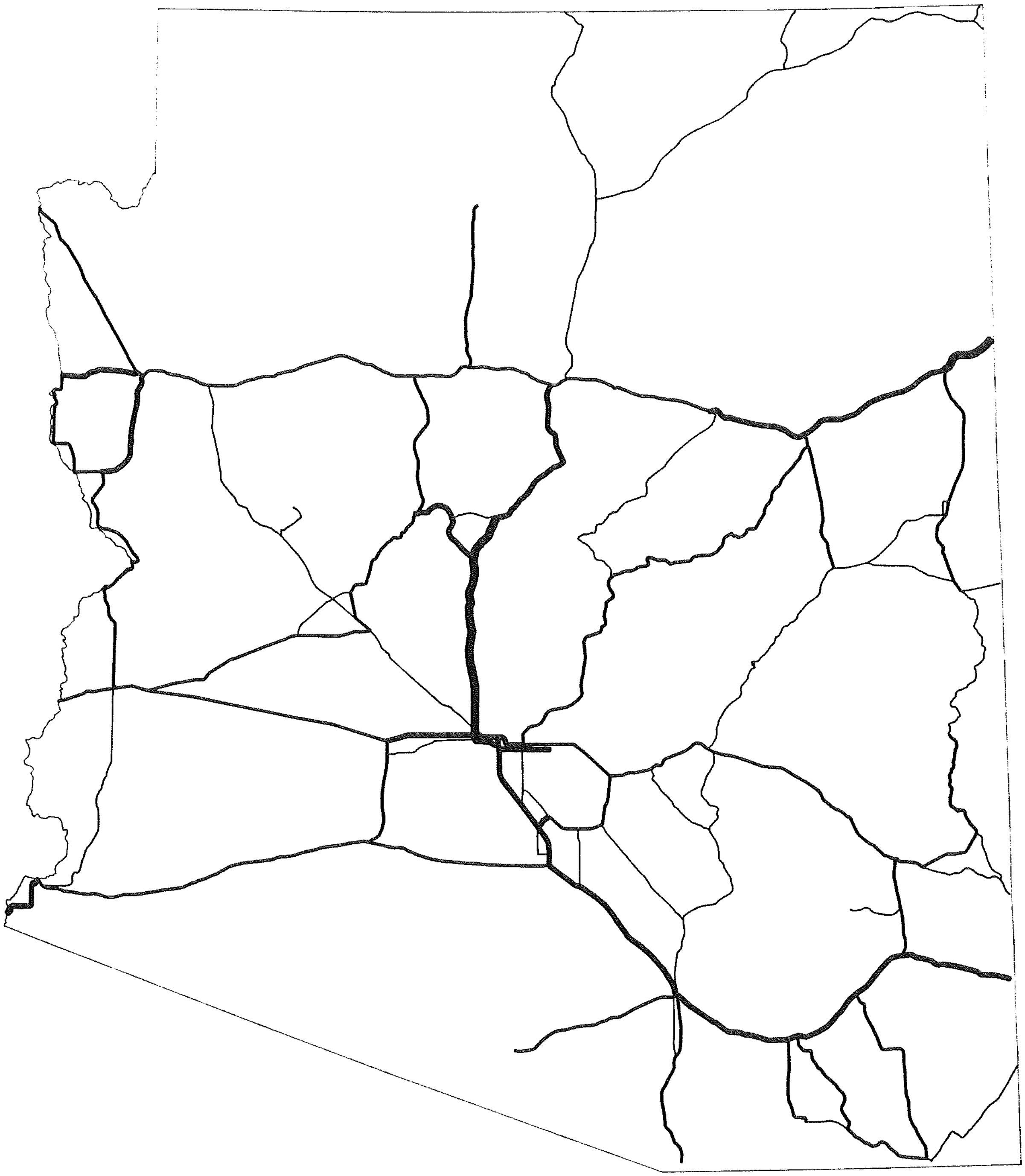


Figure 3.4

OXIDIZER

Risks of Transporting Hazardous Materials in Arizona ATRC / Dames & Moore



ANNUALIZED SURVEY

- **HIGH QUARTILE**
- MID QUARTILES
- LOWER QUARTILE
- NO DATA

Figure 3.5

GASOLINE

Risks of Transporting Hazardous Materials in Arizona ATRC / Dames & Moore

4.0 ARIZONA'S TRUCK ACCIDENT RATE

The truck accident rate for various segments of the state highway system was obtained from the Arizona Department of Transportation. Data for the years 1975, 1976, and 1977 were analyzed and averaged to obtain the rates used in this study. These average accident rates are shown in Figures 4.1 and 4.2.

Over 600 roadway segments are included in the truck accident rate data. These segments were based on the following criteria:

Intersections with major highways
Significant changes in accident rates
Jurisdictional boundaries

The average accident rates ranged from 0 to 17.31 accidents per million vehicle miles traveled. A listing of the accident rates for each segment is presented in Appendix B. These data are identified by highway route number and milepost.

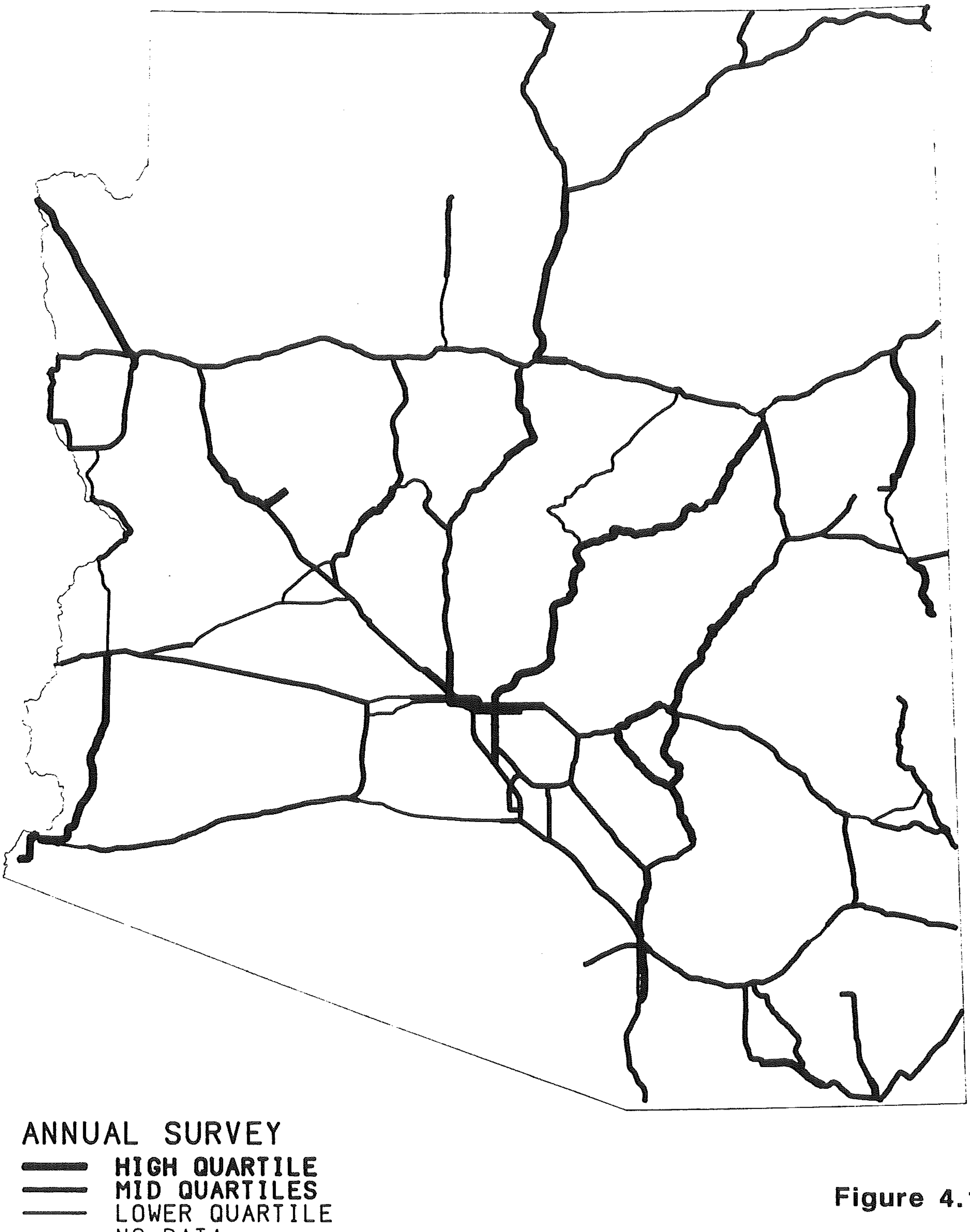


Figure 4.1

'85-'87 AVERAGE ACCIDENT RATES

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

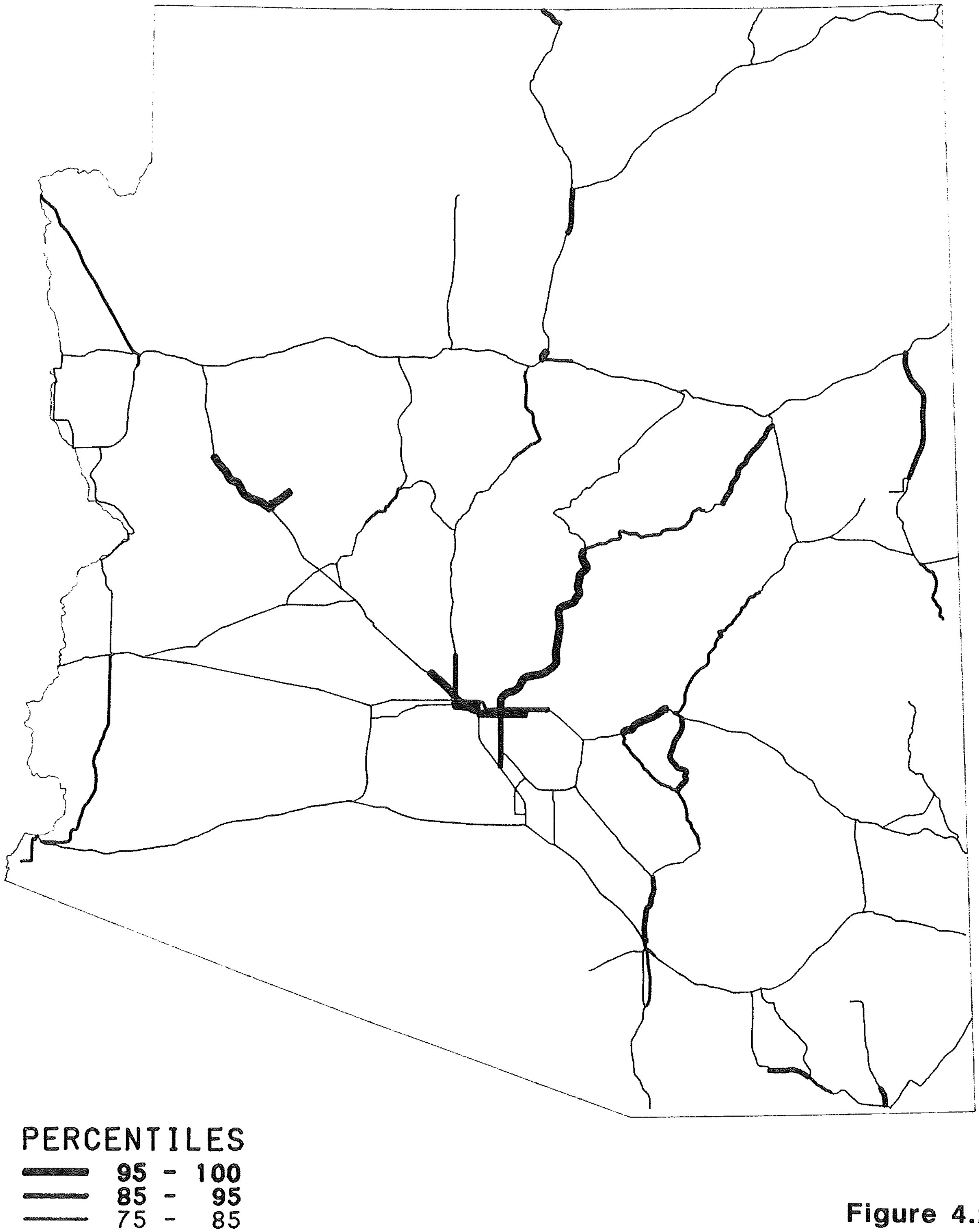


Figure 4.2

'85-'87 AVERAGE ACCIDENT RATES

Risks of Transporting Hazardous Materials in Arizona ATRC / Dames & Moore

5.0 DEMOGRAPHIC DATA

5.1 POPULATION

Population data were taken from the 1980 census summary tapes. While these data have limited geographic information, they were the best available when this analysis was conducted. The new 1990 census files will provide greater geographic resolution. Two summary levels in the 1980 summary files contain geographic centroids, these were read into the GIS and aggregated on a square mile basis. Inspection of the maximum values indicated that normalizing was required to achieve actual density.

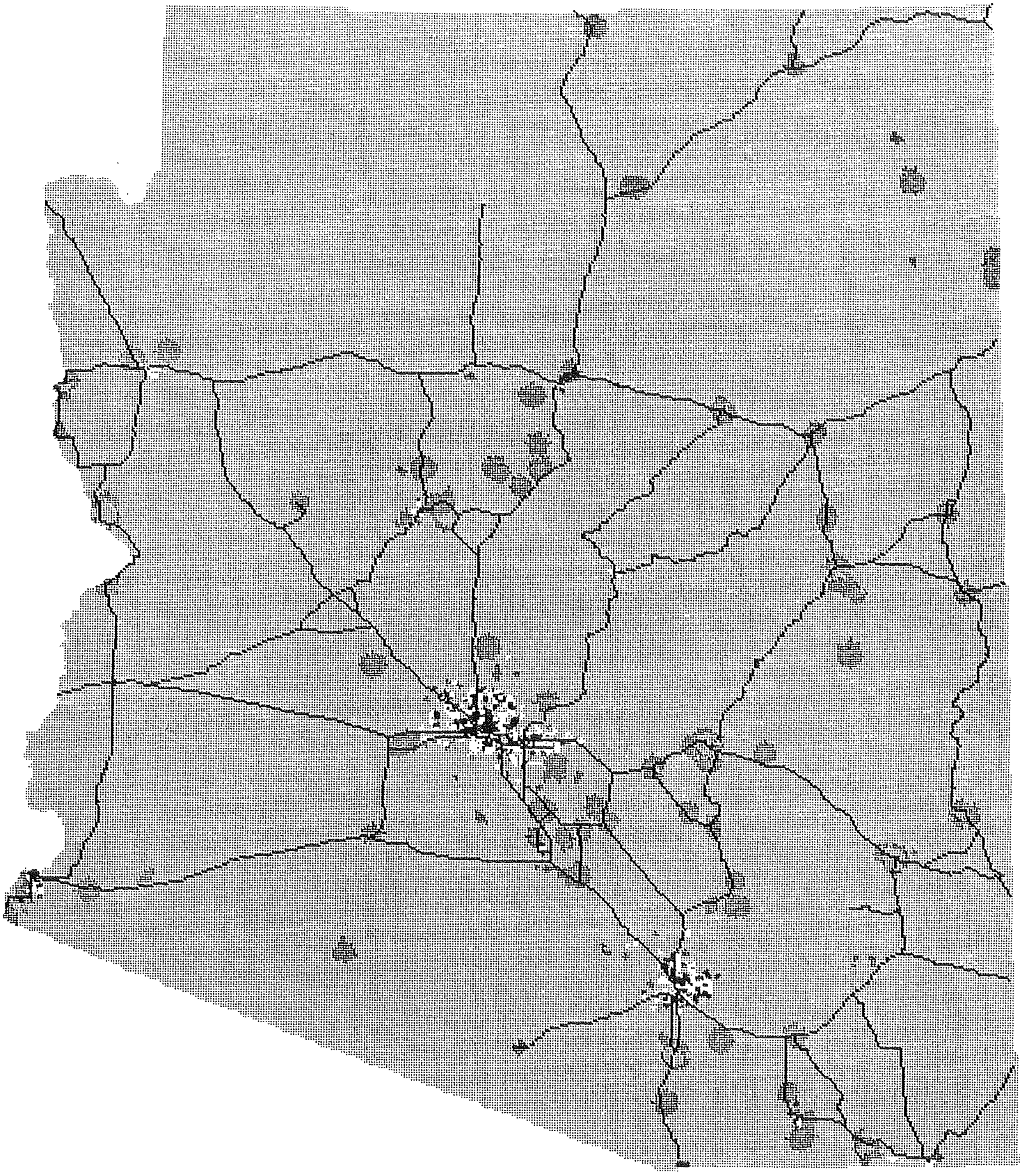
The GIS was requested to distribute the population from its inherent "point" location equally across a 5-square-mile area thereby smoothing the data and reaching a calibrated persons per square mile density matching the observed development density. In rural areas when the enumeration districts are well over 5 square miles, this population model was conservative in its overestimation of population density. The results of this process are shown in Figure 5.1.

5.2 EMERGENCY RESPONSE LOCATIONS

The primary emergency response organizations that respond to hazardous materials incidents are fire departments. A listing of fire department units was compiled from information provided from the State Fire Marshal's Office and individual fire departments. This information is illustrated on Figure 5.2.

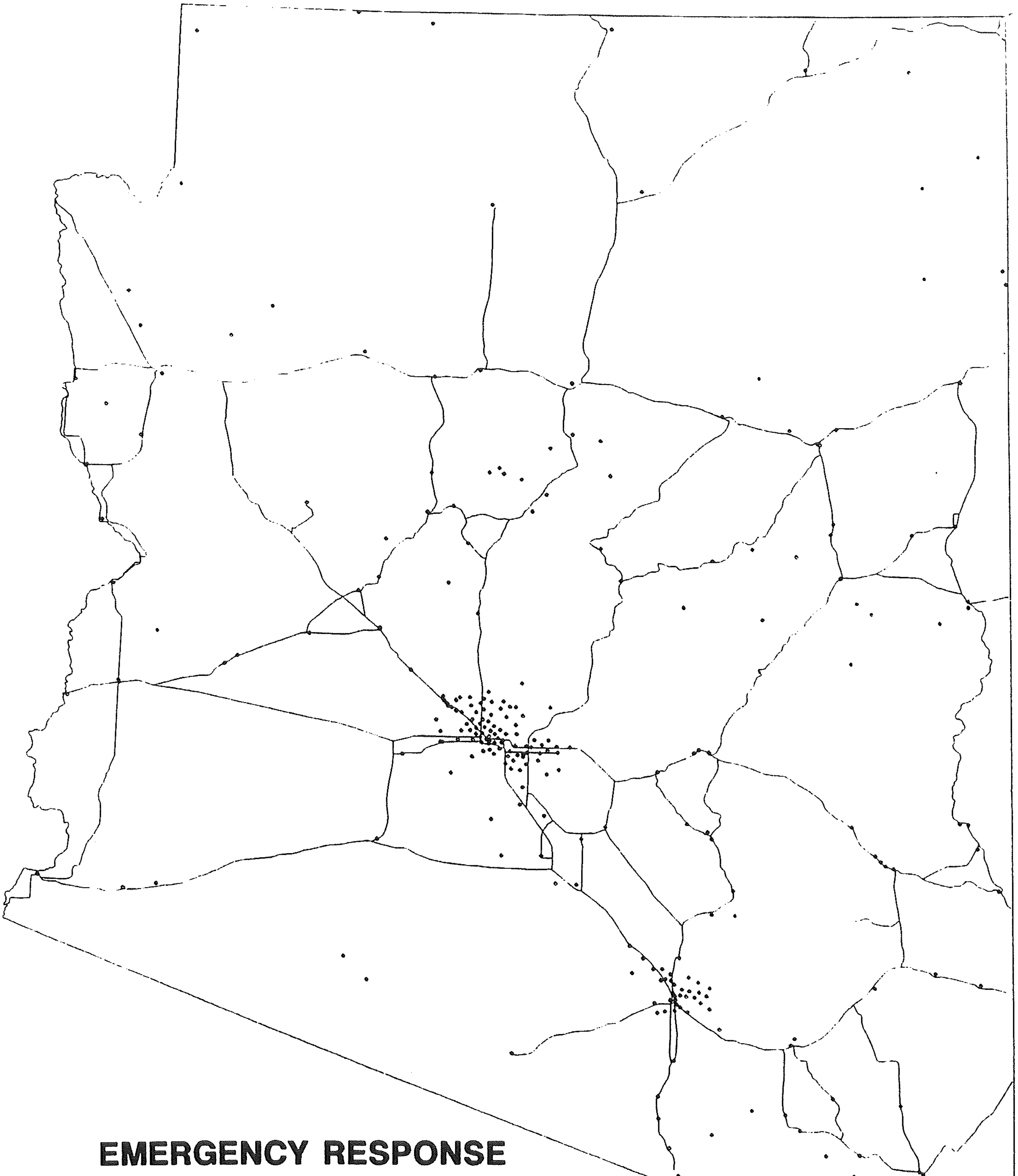
Individual fire departments may have specific response areas and may not be authorized to respond to an incident that is near to their location. For the purposes of this analysis, it was assumed that the closest emergency response unit would respond to a hazardous materials incident regardless of jurisdictional boundaries that may prohibit them from responding.

There are significant differences in the training and capability of a fire department unit to respond to hazardous material emergencies. The cities of Phoenix and Tucson have units specifically trained to respond to hazardous materials incidents. Consistent information regarding the size and training of each unit and their capability to respond to different types of hazardous materials incidents was not available at the time this analysis was conducted. Therefore, for the purposes of this analysis, it was assumed that all fire department units were capable of responding to any type of hazardous material emergency. In any case, some level of response will be obtained for a nearby emergency response unit if only to identify and characterize the incident as one requiring additional 'specialist' attention.



POPULATION DENSITY
Transporting Hazardous Materials In Arizona

Figure 5.1
ATRC/Dames & Moore



EMERGENCY RESPONSE LOCATIONS

Transporting Hazardous Materials In Arizona

Figure 5.2
ATRC/Dames & Moore

6.0 MODELING METHODOLOGY

The objective of modeling for this study is to obtain a comparative analysis of the risks for the entire state highway system. The spatial relationships are considered more important than the specific values obtained, that is the relative risks across the network are the principal objective.

Models can be used for varying purposes. For this study, the risk model is used as an analysis tool for understanding the data and allows for planning activities on the network. As such, the entire network is modeled. Alternative models can be described as fixed specific location models and real time event models. Specific location models can typically be calibrated with annual meteorological data incorporating the probability of wind direction and speed. Event models require actual meteorological data and are used in predicting the consequence of an actual event in emergency response functions.

The basic risk model is described in Federal document FHWA-IP-80-15, Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials. In consists of:

The frequency of hazardous material shipments

The probability of an event at a location

The nature of dispersion based on the material characteristics

The density of population in the area

The nature of the incident consequences

For this study it was impractical to incorporate meteorological conditions for over 100,000 square miles of Arizona. Since the severity of the event is also relative, we chose to externalize this factor from the model itself. The severity consequence is not a spatial factor, while all other components of the model are. The ability to externally weight the final model results allows for varying the consequences based on medical, chemical and public perception of the event type.

6.1 DATABASE STRUCTURE

Spatial analysis requires locational diversity. For this project the road network provides the framework for analysis. The federally aided highways in Arizona were digitized based on the USGS state series maps which are in a LAMBERT projection. The state boundaries were obtained from digital data prepared for the 1980 census.

The major data integration occurred in a combination of tabular traffic data from state surveys with the geographic network. The digitized network consisted of the unique segments between intersections/interchanges making up the state highway system. The tabular data typically referred to only the estimated volumes of hazardous materials by route segment for each major category of hazardous material. The database model was specified for each origin/destination which allocated the surveyed trip to the constituent segments in the network. Essentially each survey shipment was projected into unique segment records in the detailed tabular database.

Accident data from the state records were available in more detail than were the hazardous material transport data. Within the GIS, the segments were coded in a hierarchy. This hierarchy allowed flexibility to analyze segments as a whole when using the tabular data on materials shipments and also to assess the more detailed accident data on such segments. Typically the accident data were available with subsegments defined by major state and county road intersections/interchanges. Most of the highway data segments were classified into three to five subsegments with corresponding historic accident rates for truck traffic for each subsegment.

6.2 MODEL STRUCTURE

The data were entered into the Geographic Information Management System (GIMS), developed by Dames & Moore. GIMS is a comprehensive vector and raster based system which allows the integration of cell based data and point data and linear data.

Five models, representing five typical exposure pathways, were constructed based on the generic evaluation equation of four spatially varying components:

Component	Evaluation
Accident rate	Incident probability
Shipment frequency	Hazard
Population affected	Risk
Response time	Vulnerability

The generic formula for evaluation consisted of the following:

Absolute Hazard	= (R) (F)
Population at Risk	= (R) (F) (P)
Vulnerability	= (R) (F) (P) (T)

Where

R Accident rate by subsegment. These data are drawn directly from the accident rate table.

F Shipment frequency by highway segment and type of hazardous material. These data are drawn from the previous survey data.

P Population affected. Determined by the local population density and modified by the material specific effects radius.

T Response time. Determined by nearness of fire stations as modeled over the state highway network.

Documentation on the Model and its operation is presented in Appendix D, Risk Assessment.

6.3 HAZARD ANALYSIS

The initial component of the model provides a comparison of the absolute hazard by route segment which is calculated by multiplying the truck accident rate by the volume of hazardous material transported. This information is presented in Figures 6.1 through 6.5 for the five scenarios analyzed.

6.4 RISK ANALYSIS

The population affected by a hazardous materials incident is calculated by evaluating the population within an impact area. The impact area varies depending on the type of hazardous material being transported and the exposure pathway. The impact radius was obtained from report FHWA-IP-80-15, Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials. The following pathway models were utilized using the GIMS command structure.

Model	Representative Material	Impact Radius In Miles
Inhale	Nonflammable Gas	2.0
Blast	Explosives	0.5
Toxic	Poisons	0.3
Contact	Corrosives	0.7
Combust	Gasoline (flammable)	0.5

The population at risk index is then calculated by multiplying the truck accident rate by the frequency of hazardous material by the population affected. The outputs of the population at risk analyses are presented in Figures 6.6 through 6.10.

6.5 VULNERABILITY ANALYSIS

The geographic locations of fire stations were included in the map database. Utilizing the federally aided highway network as the principal access from the fire stations to potential incidents, both the network and the intervening space were modeled for probable response time. The highway network was set to support a 50-mph effectiveness speed; urban and rural areas off the principal network were set to an effective 25-mph speed. A base mobilization of 5 minutes was also assumed. The model allows the user to set any of these values for alternative assessments. Based on the above parameters, a maximum of 76 minutes for any segment of the network was obtained and a maximum of 136 minutes for any point in the state.

Figure 6.11 presents the results of the response time analysis. With this information, the model can calculate the relative vulnerability for each route segment by multiplying the truck accident rate by the volume of hazardous material by the population affected by the response time index. A response time index which ranged from 1 to 5 was used instead of the actual response time in minutes because using actual response time gave too much weight to response time vis a vis population at risk. The response time index was calculated as follows:

Response Time Index	Actual Response Time
1	Less than 15 minutes
2	16 to 30 minutes
3	31 to 45 minutes
4	46 to 60 minutes
5	> 60 minutes

The results of the vulnerability analysis of the five different categories of exposure are shown on Figures 6.12 through 6.16.

6.6 COMPOSITE ANALYSIS

The results from the analysis of the different types of hazardous materials can be combined to obtain a combined or composite risk. The model has the ability to weight the outputs of the analysis of different types of hazardous materials depending on their relative hazard to one another. Other variables, such as the sensitivity of the vulnerability index, can also be easily changed to calibrate the model to specific situations. Figures 6.17 through 6.19 present the composite hazard, composite risk and composite vulnerability of the five models assuming each model is of equal weight.

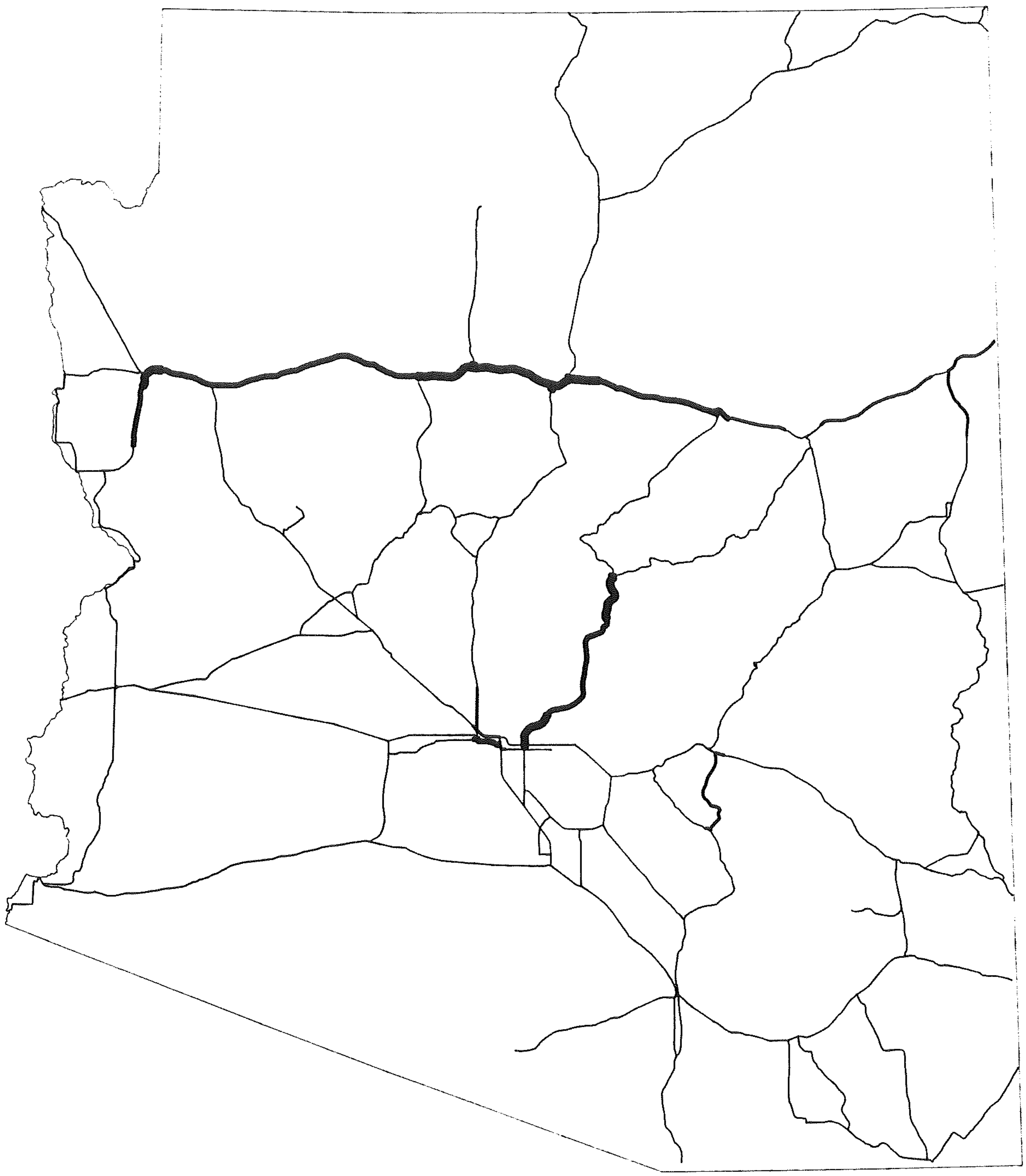


Figure 6.1

BLAST HAZARD

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

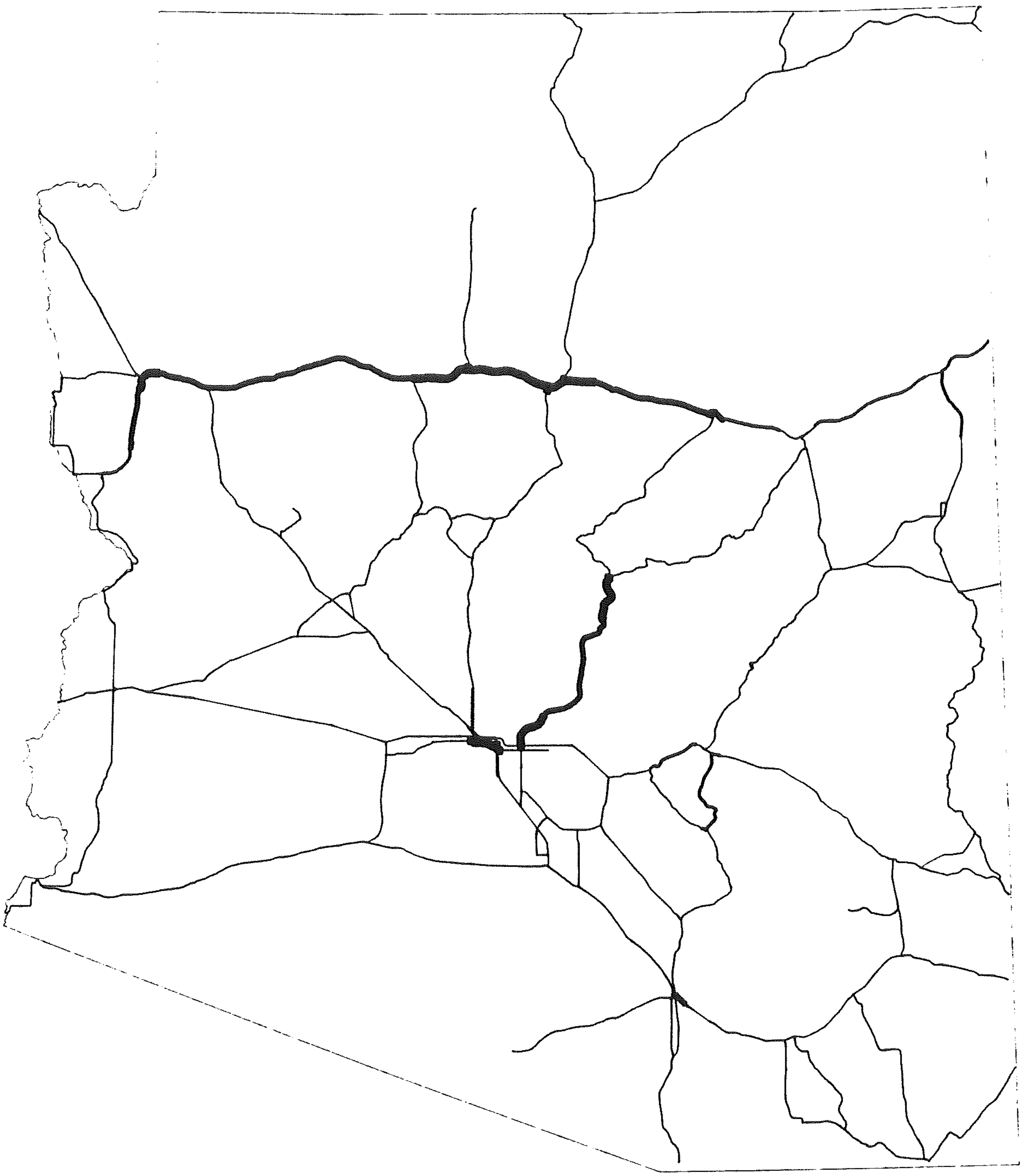


Figure 6.2

CONTACT HAZARD

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

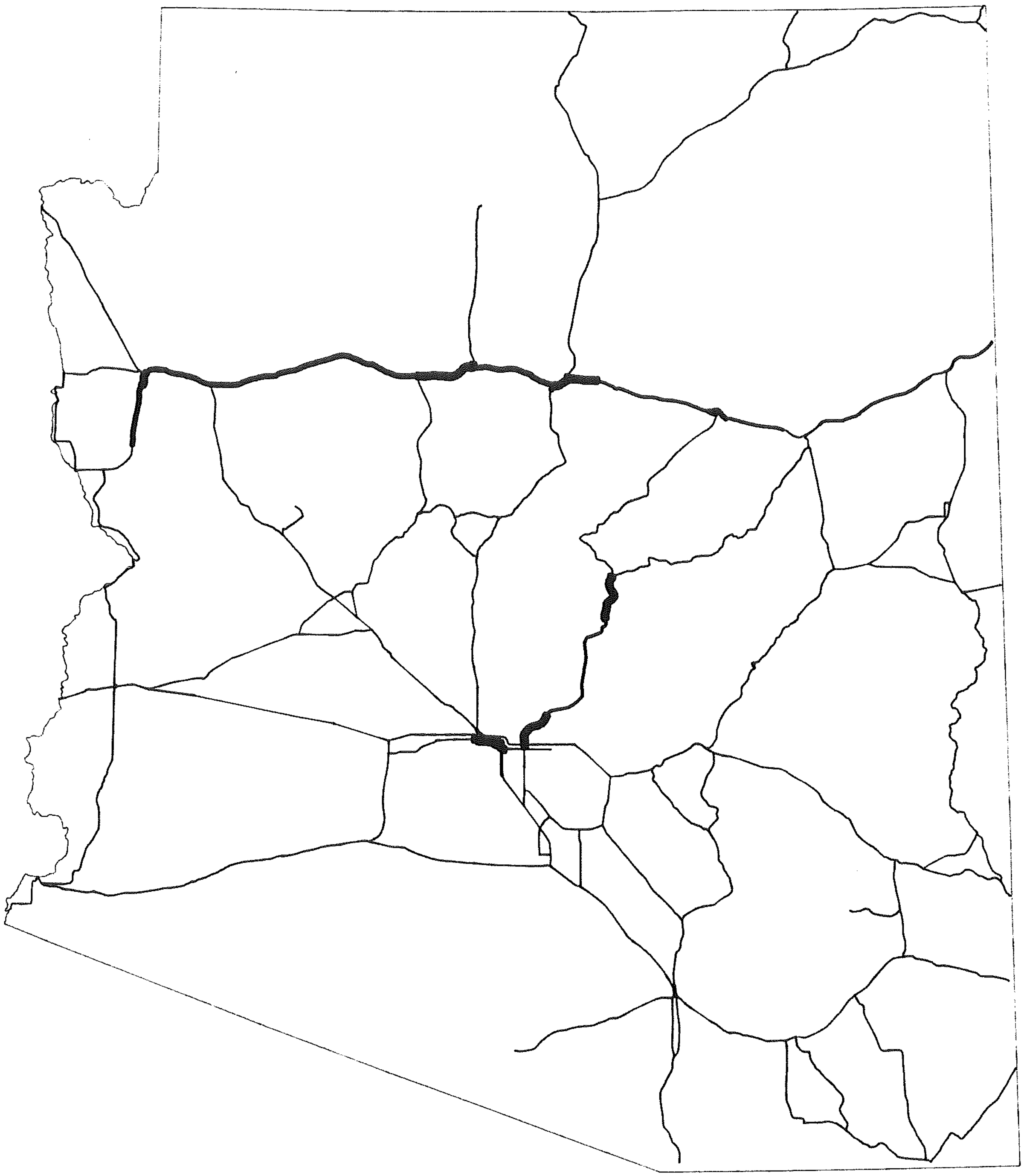


Figure 6.3

TOXIC HAZARD

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

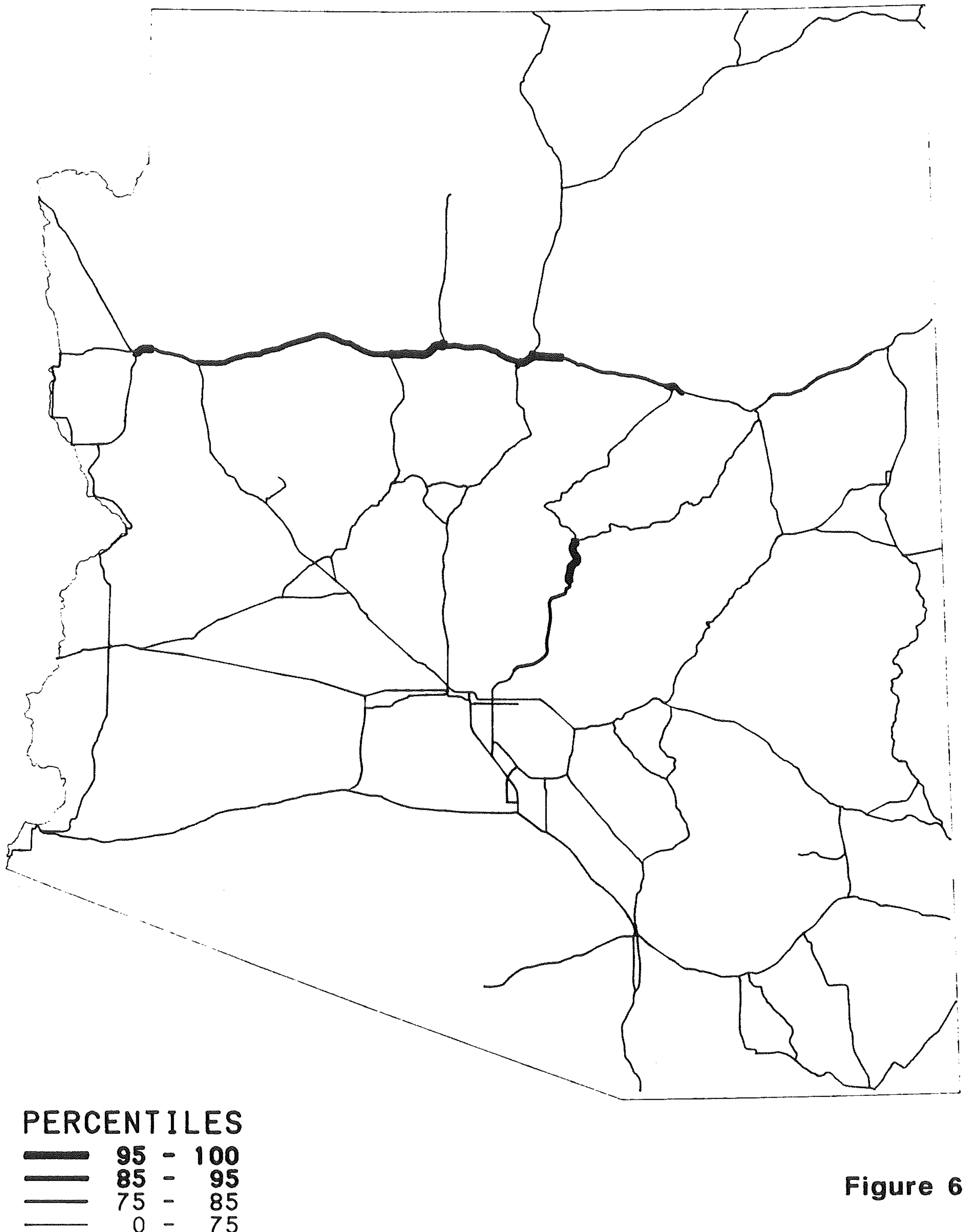


Figure 6.4

INHALATION HAZARD

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

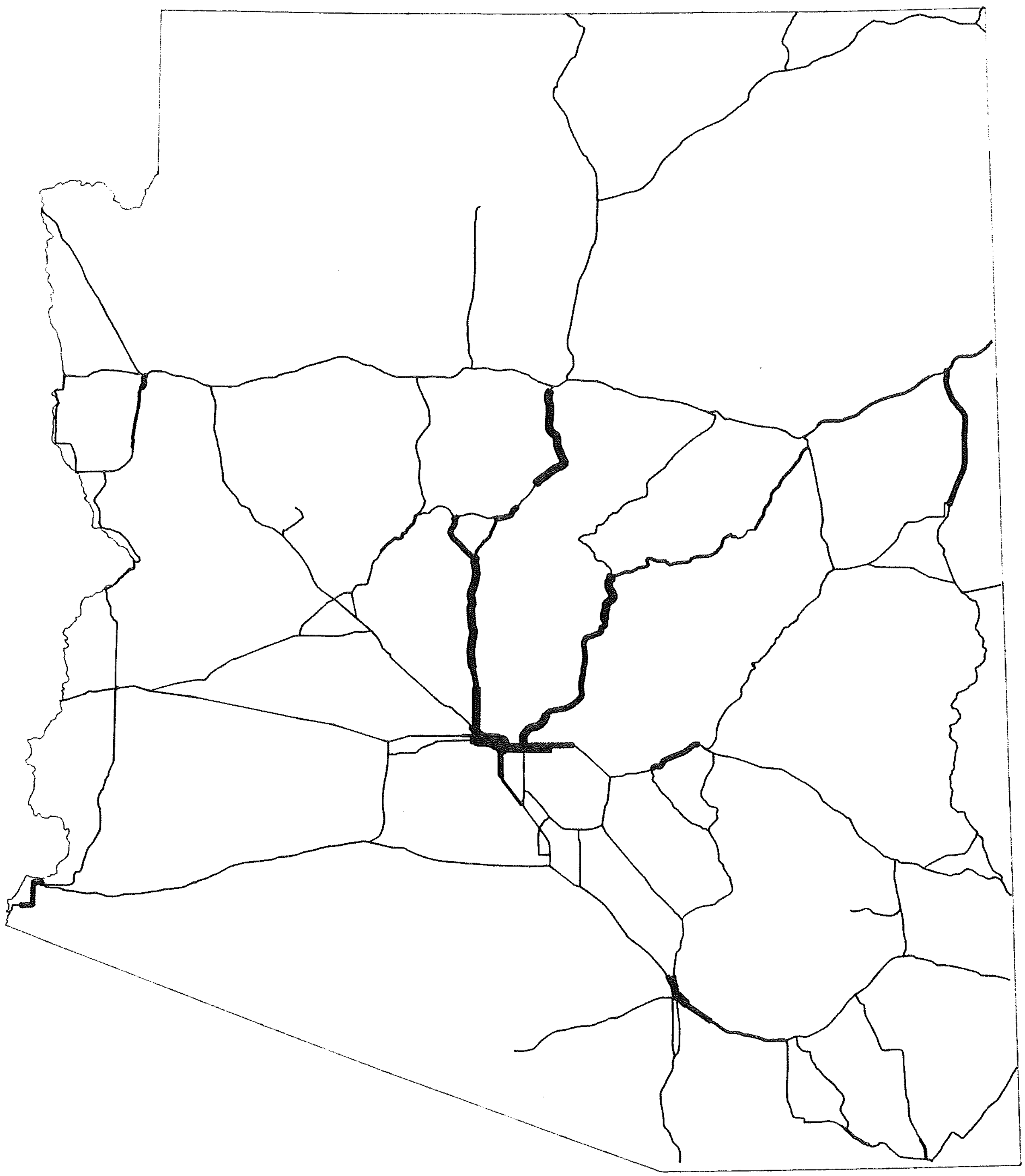


Figure 6.5

COMBUSTION HAZARD

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

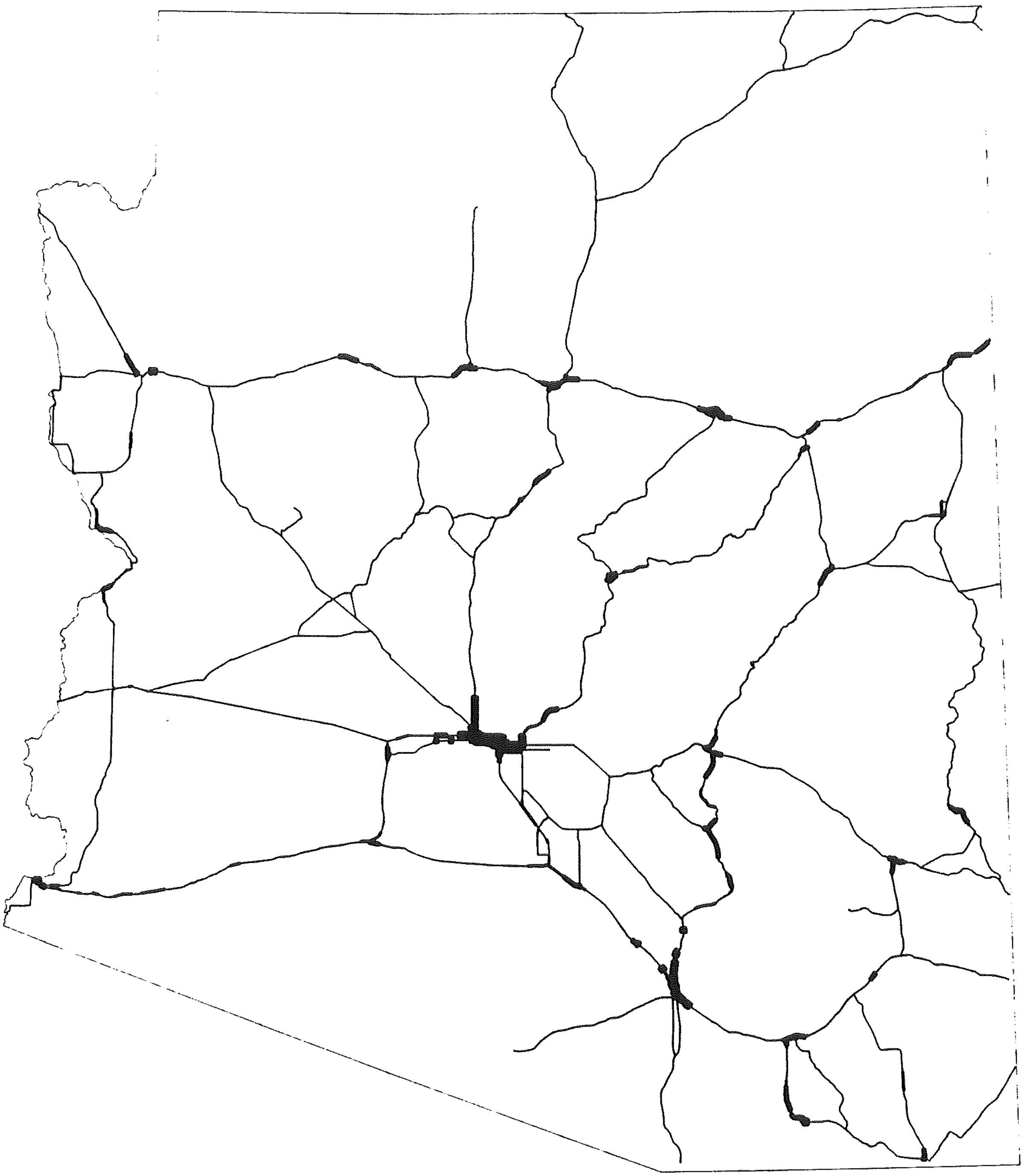


Figure 6.6

BLAST RISK

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

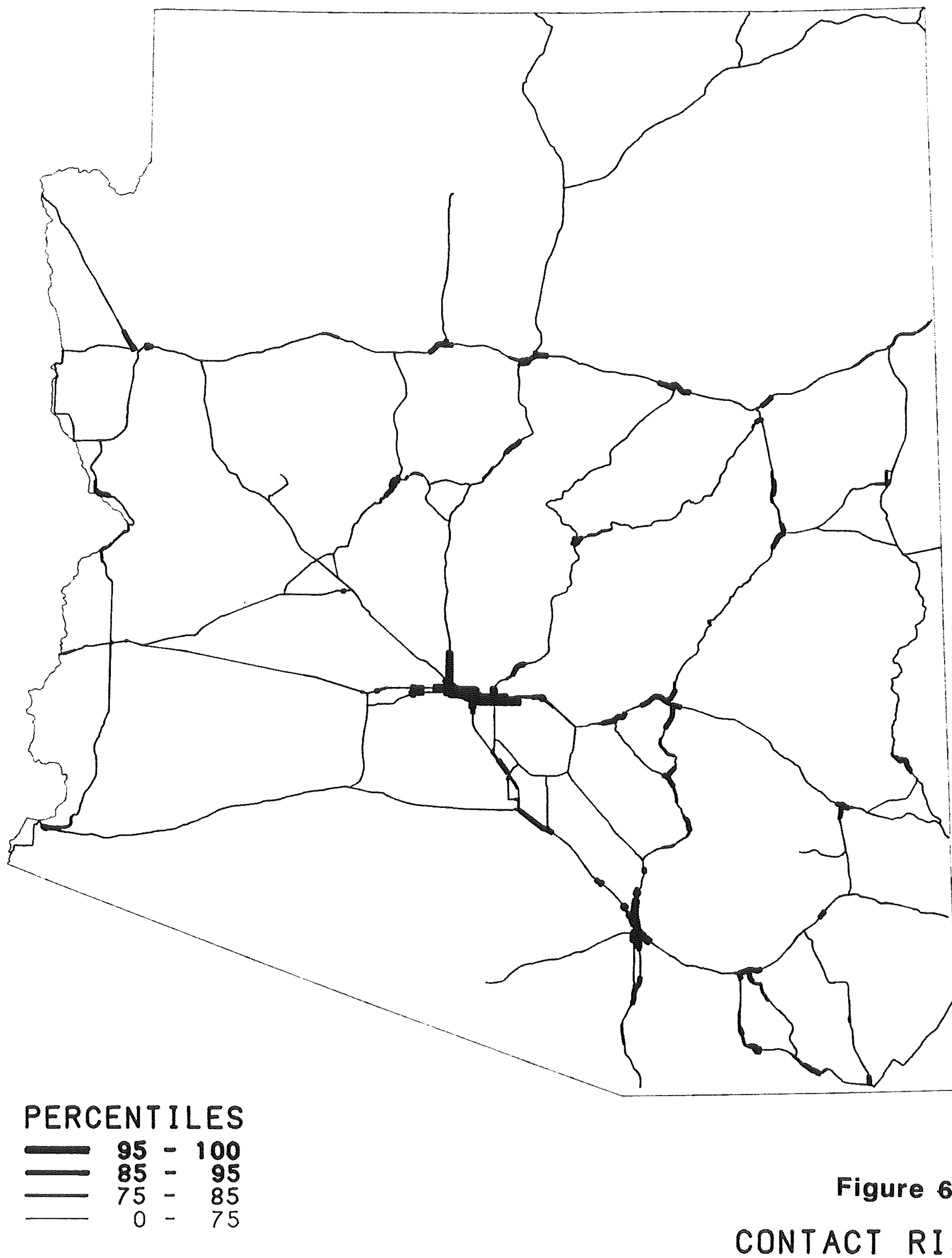


Figure 6.7

CONTACT RISK

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

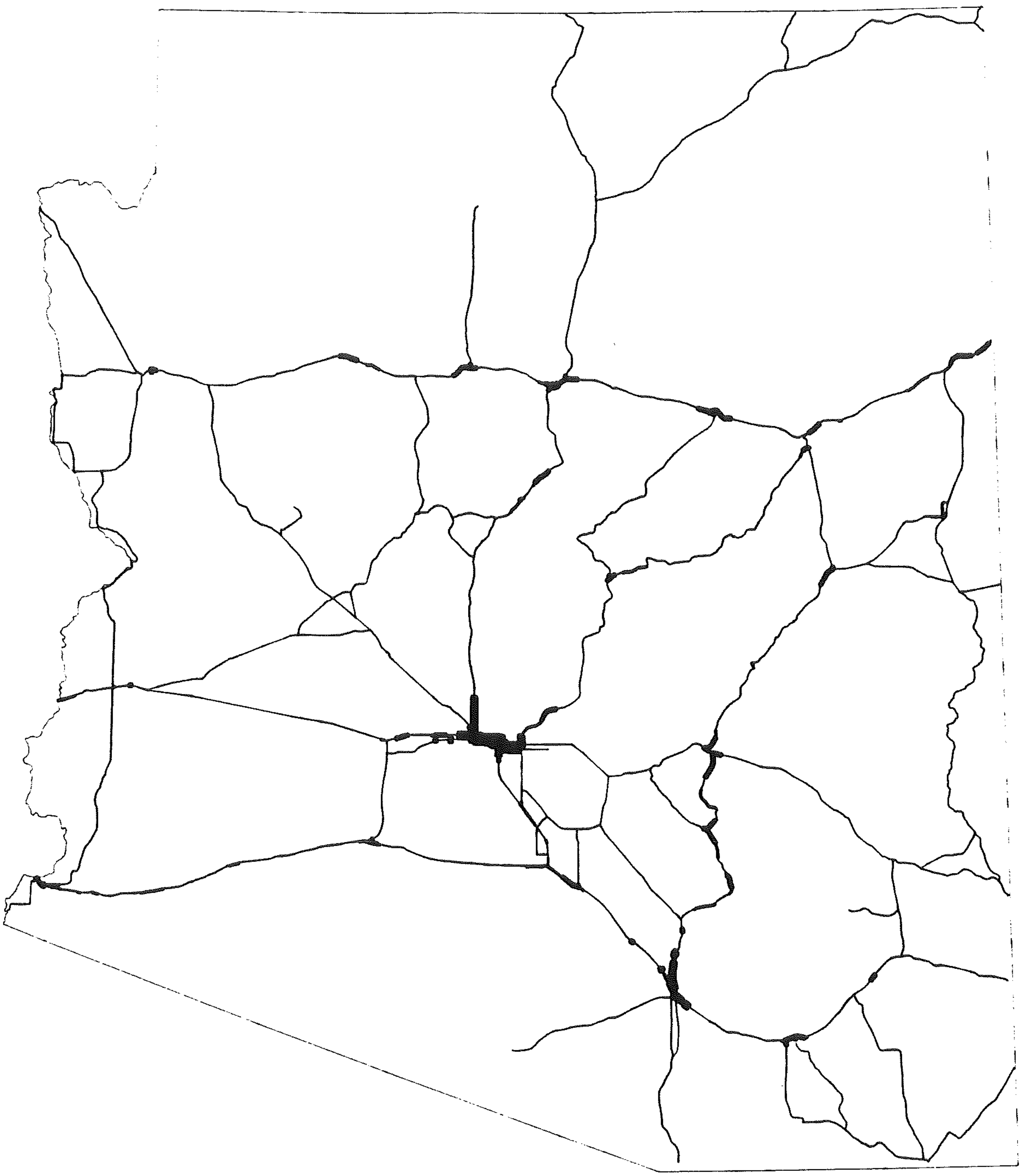


Figure 6.8

TOXIC RISK

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

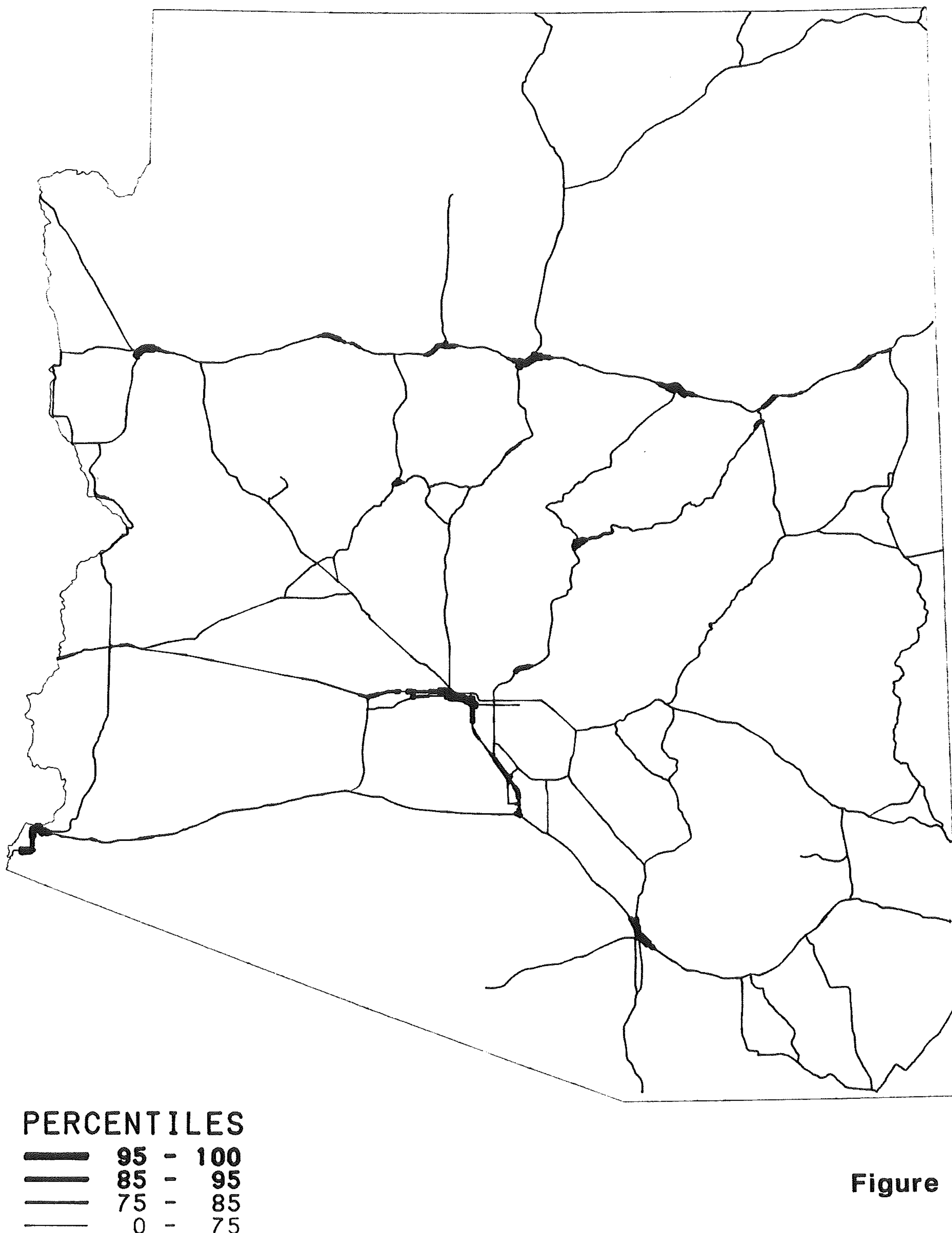


Figure 6.9

INHALATION RISK
Risks of Transporting Hazardous Materials in Arizona
ATRC / Dames & Moore

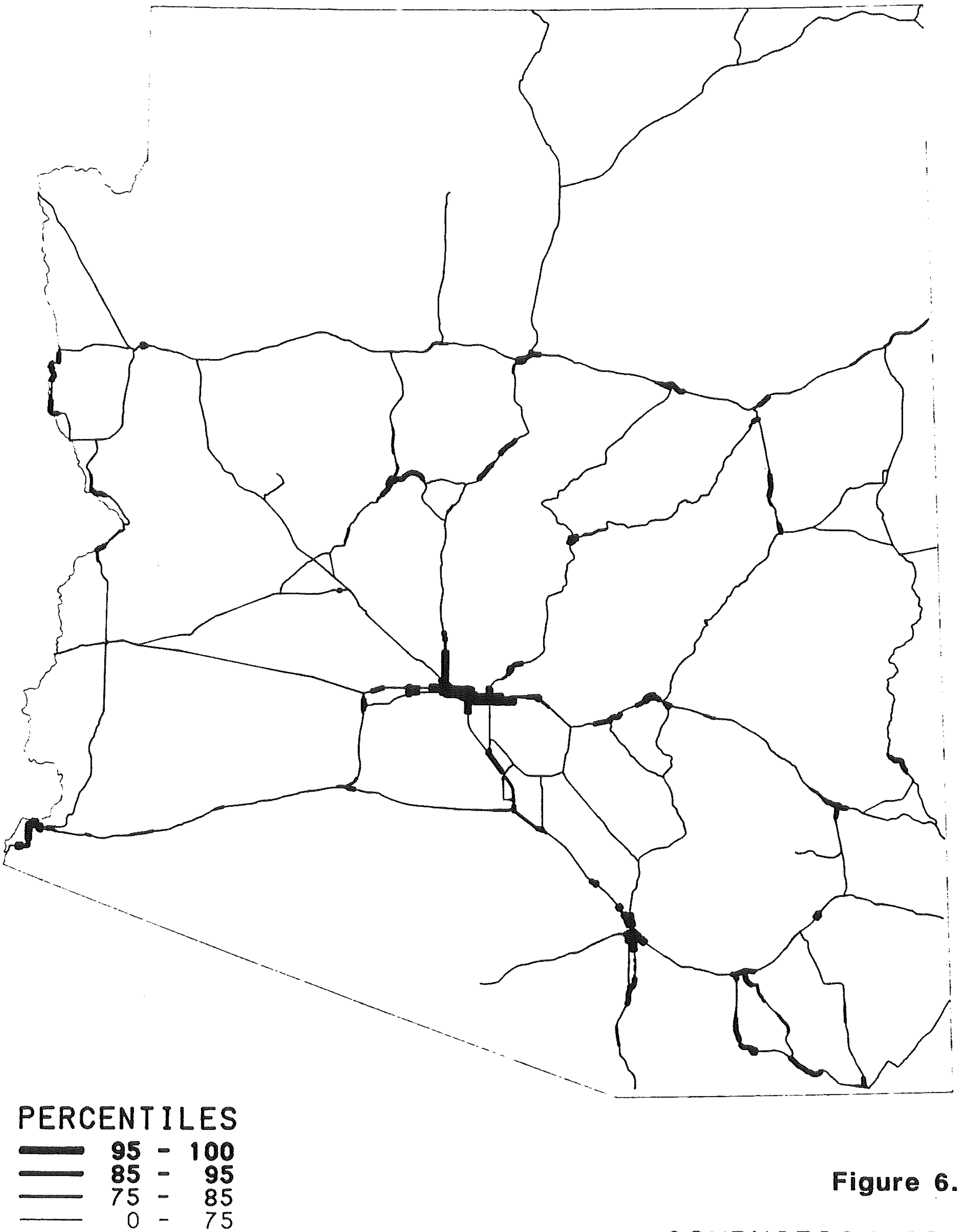
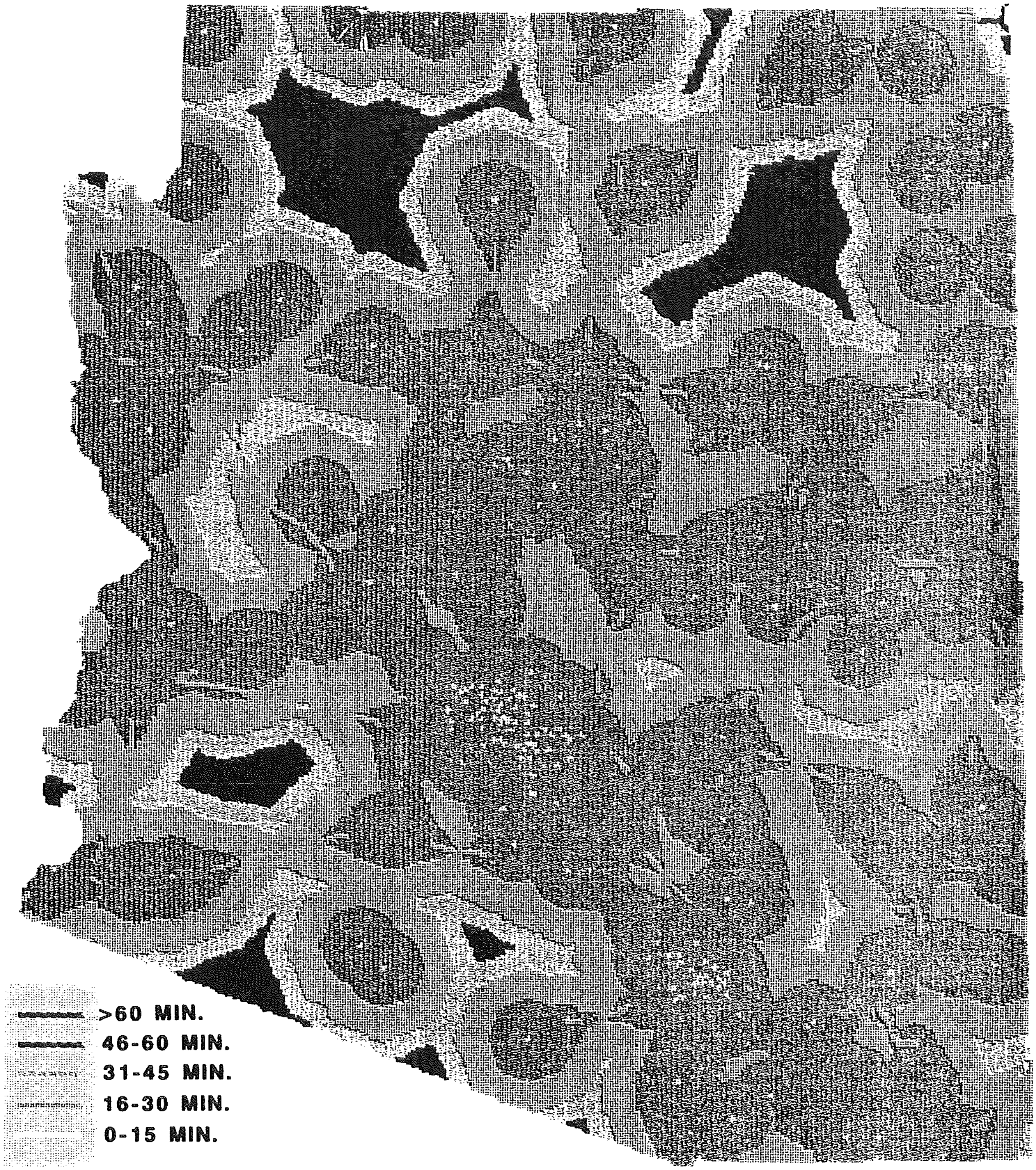


Figure 6.10

COMBUSTION RISK

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore



EMERGENCY RESPONSE TIMES
Transporting Hazardous Materials In Arizona

Figure 6.11
ATRC/Dames & Moore

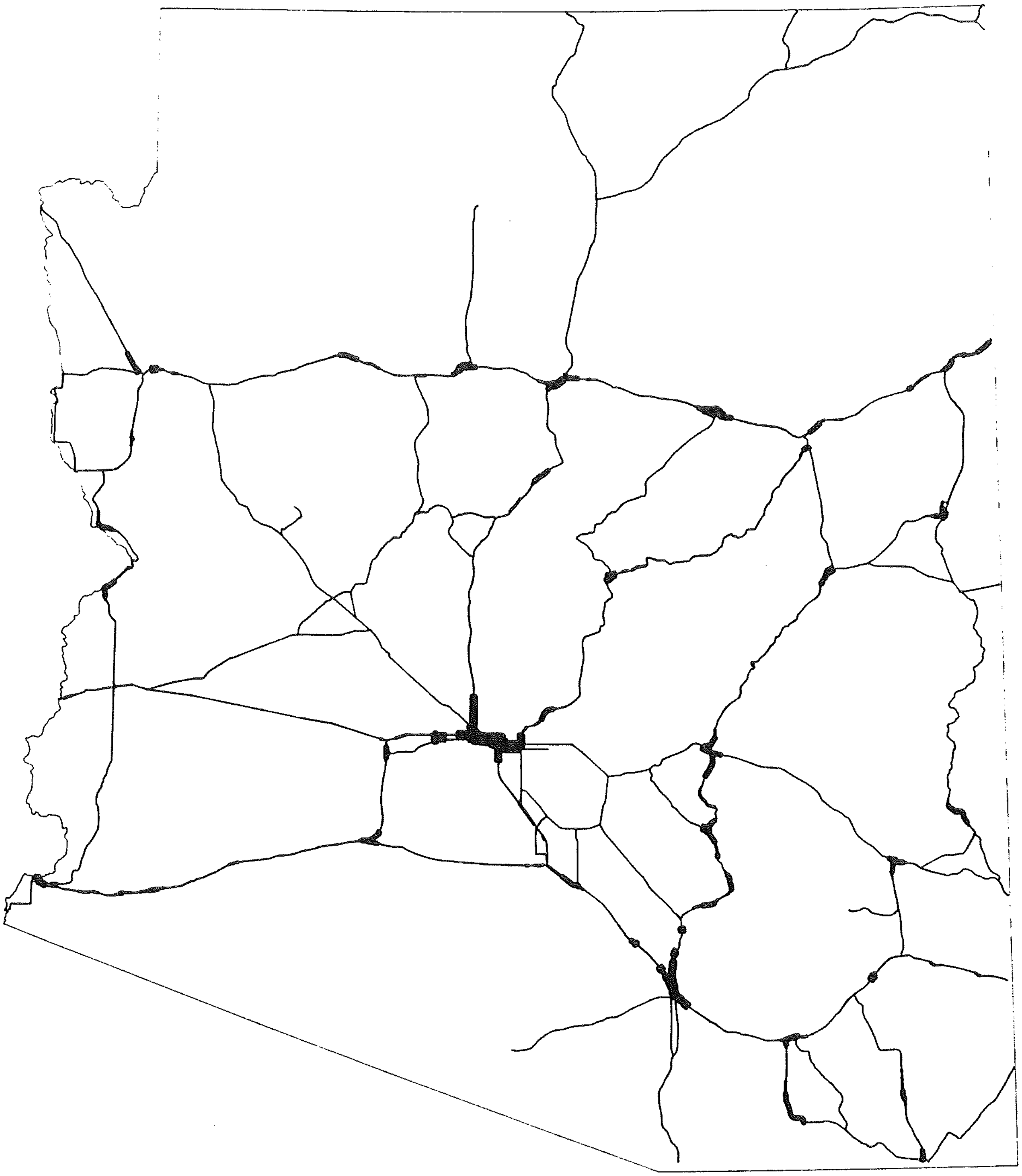


Figure 6.12

BLAST VULNERABILITY

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

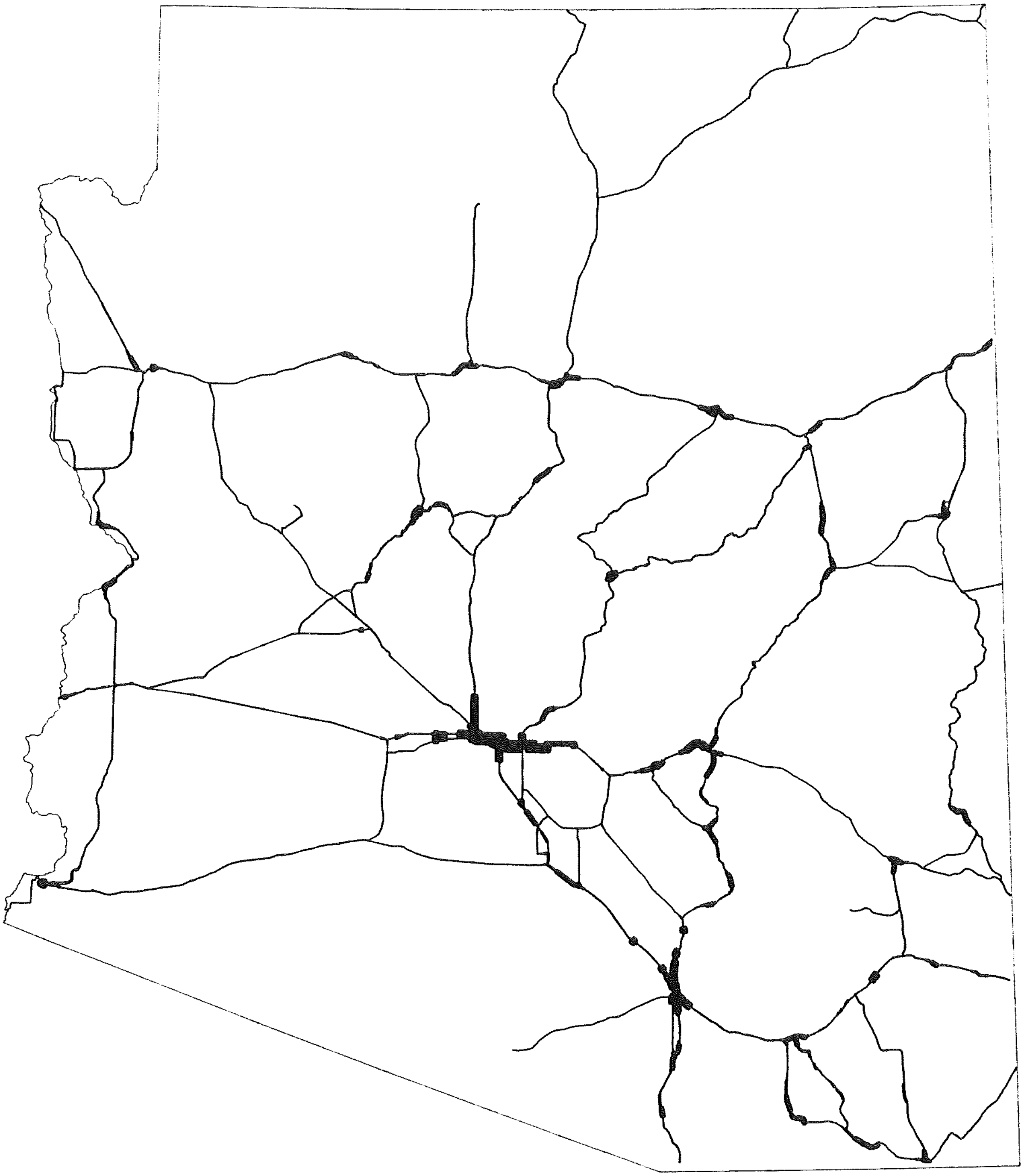


Figure 6.13

CONTACT VULNERABILITY
Risks of Transporting Hazardous Materials
in Arizona ATRC / Dames & Moore

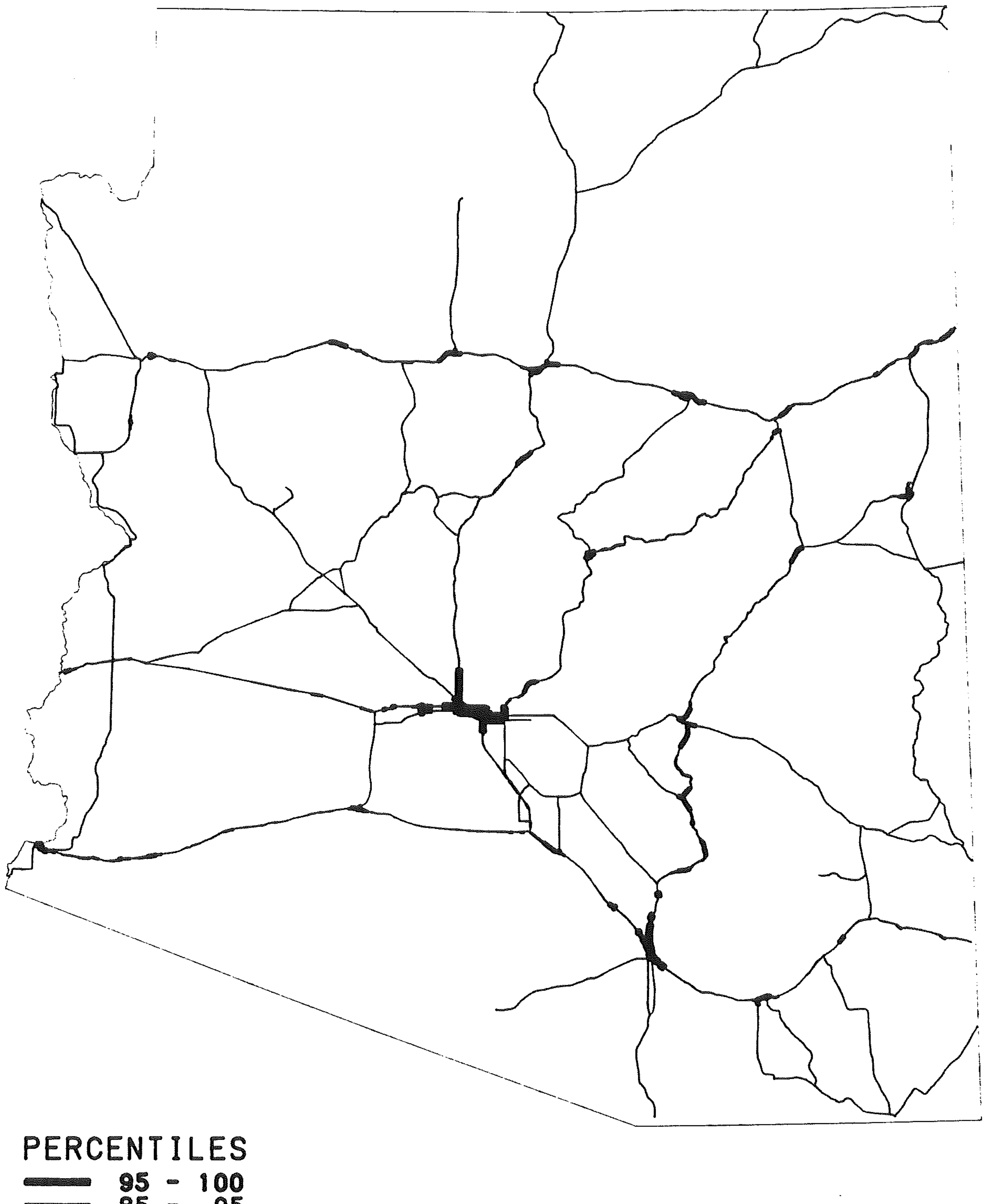


Figure 6.14

TOXIC VULNERABILITY
Risks of Transporting Hazardous Materials in Arizona
ATRC / Dames & Moore

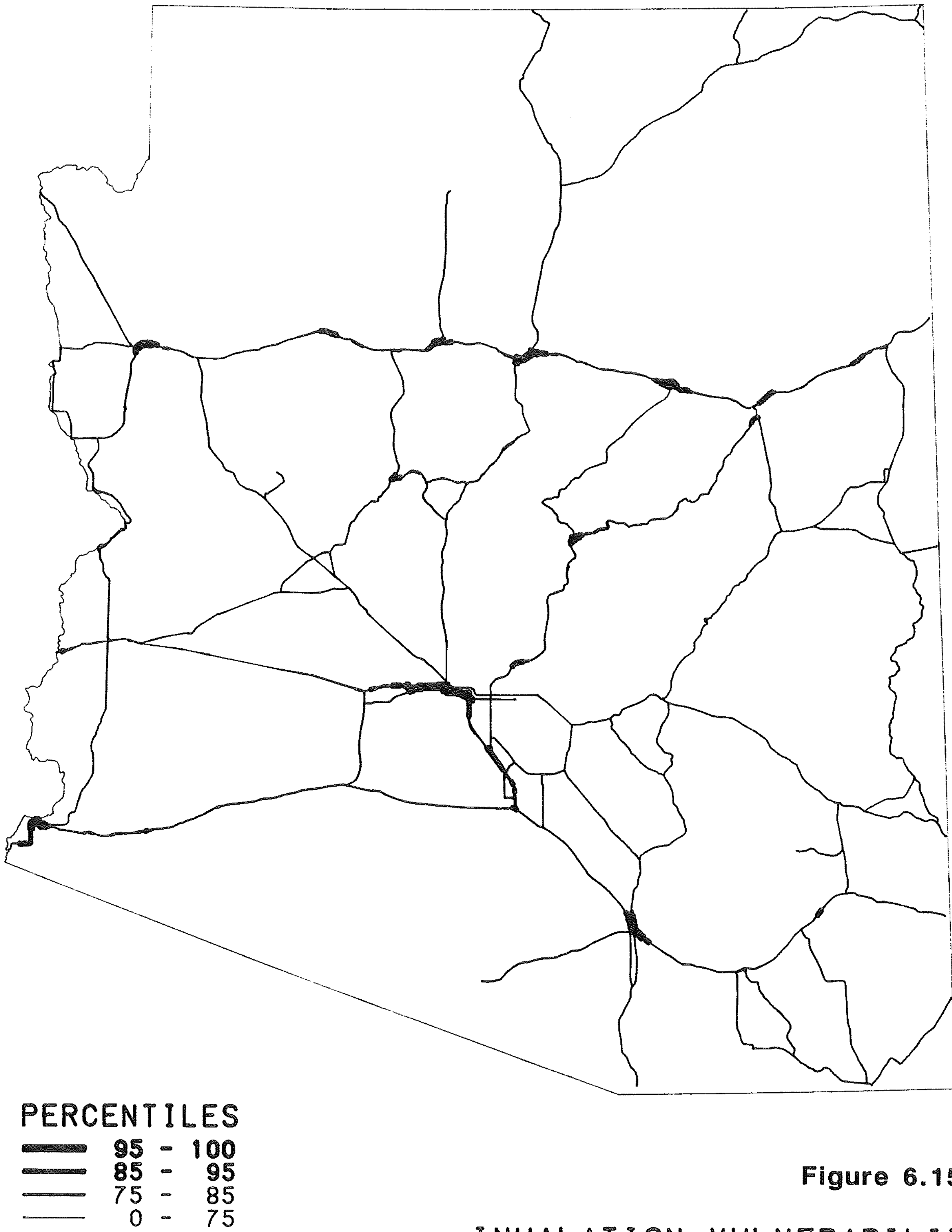


Figure 6.15

INHALATION VULNERABILITY
Risks of Transporting Hazardous Materials in Arizona
ATRC / Dames & Moore

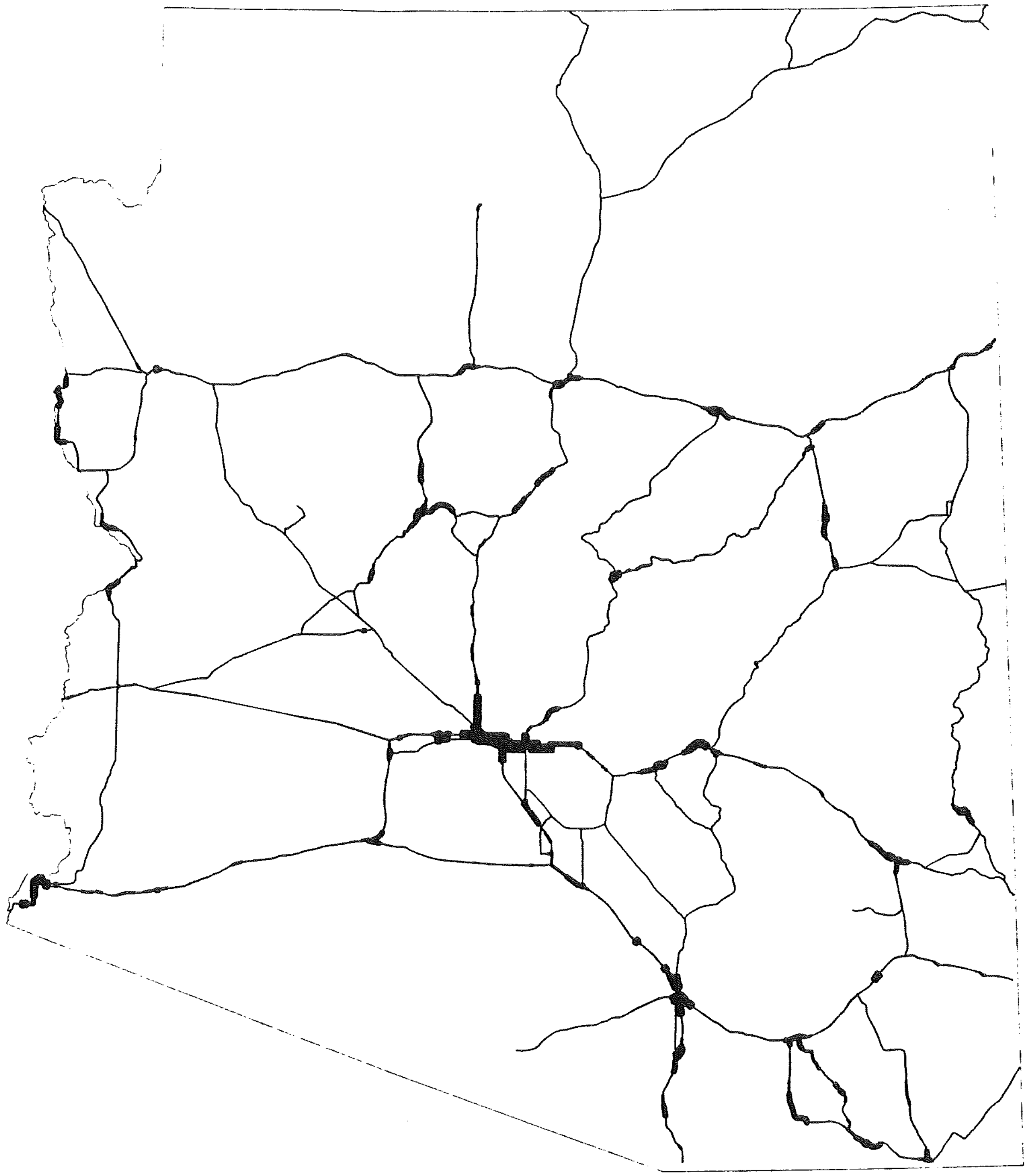
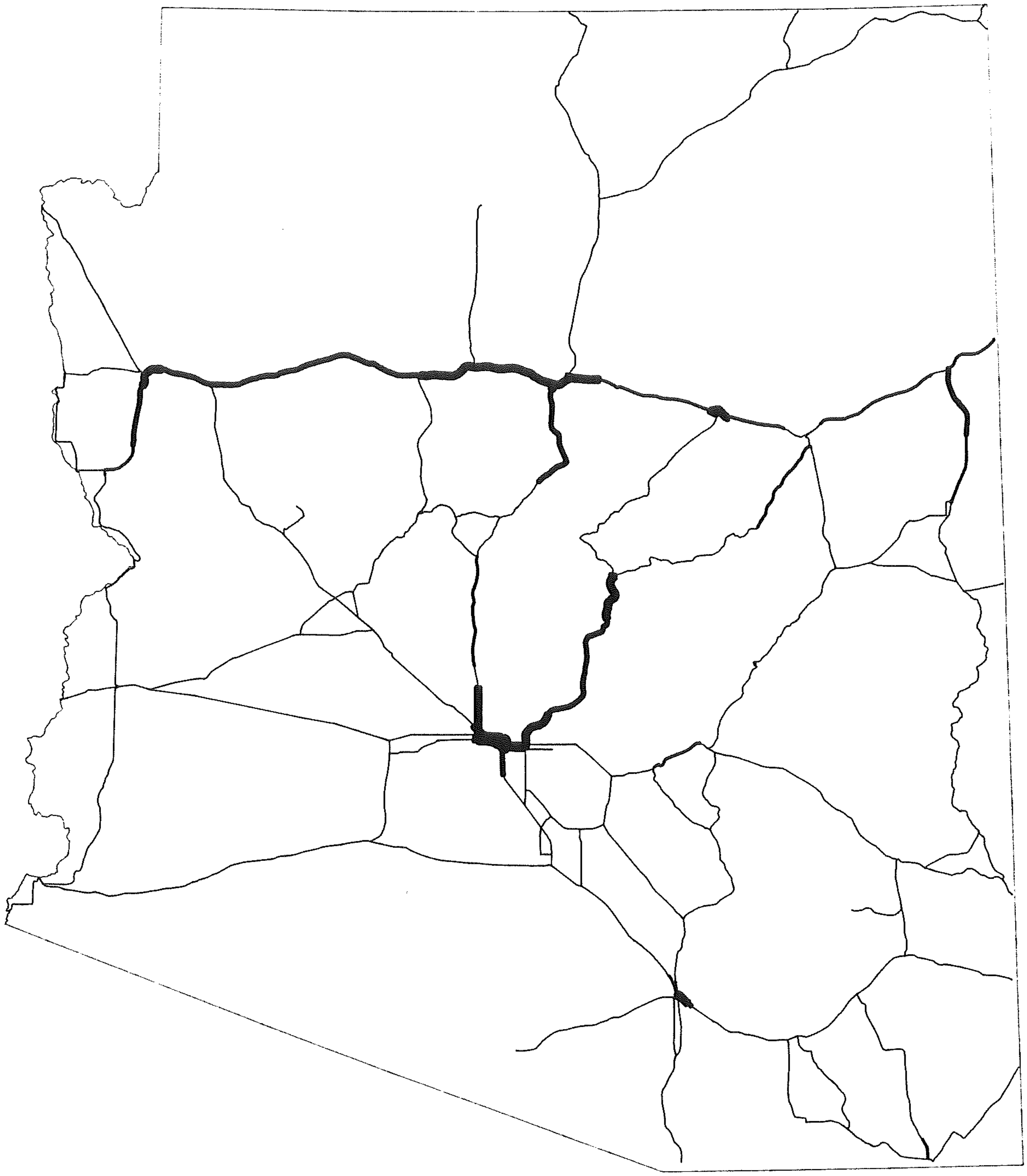


Figure 6.16

COMBUSTION VULNERABILITY

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore



PERCENTILES

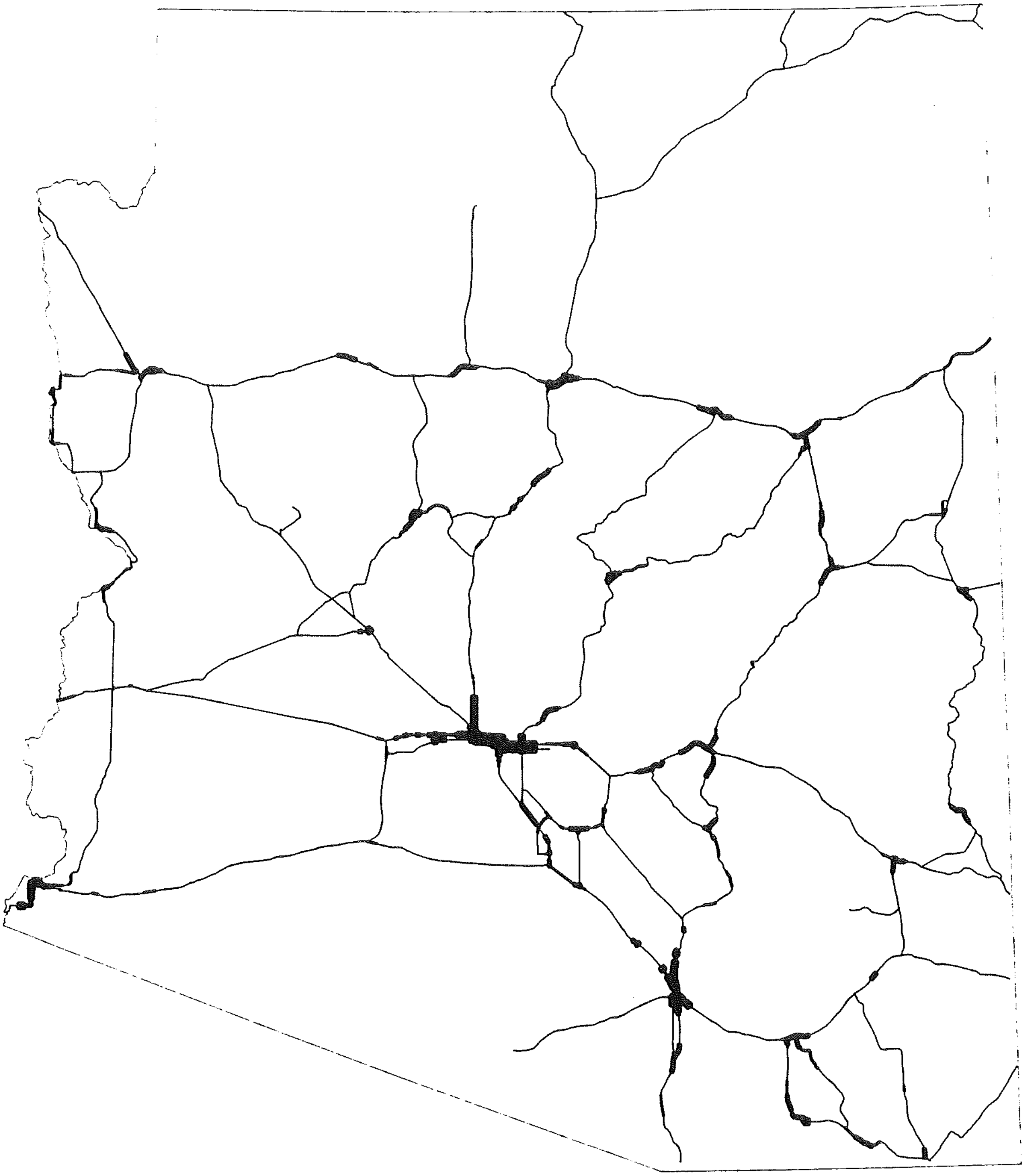
95 - 100
85 - 95
75 - 85
0 - 75

Figure 6.17

COMPOSITE HAZARD

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore



PERCENTILES
95 - 100
85 - 95
75 - 85
0 - 75

Figure 6.18

COMPOSITE RISK

Risks of Transporting Hazardous Materials
in Arizona ATRC / Dames & Moore

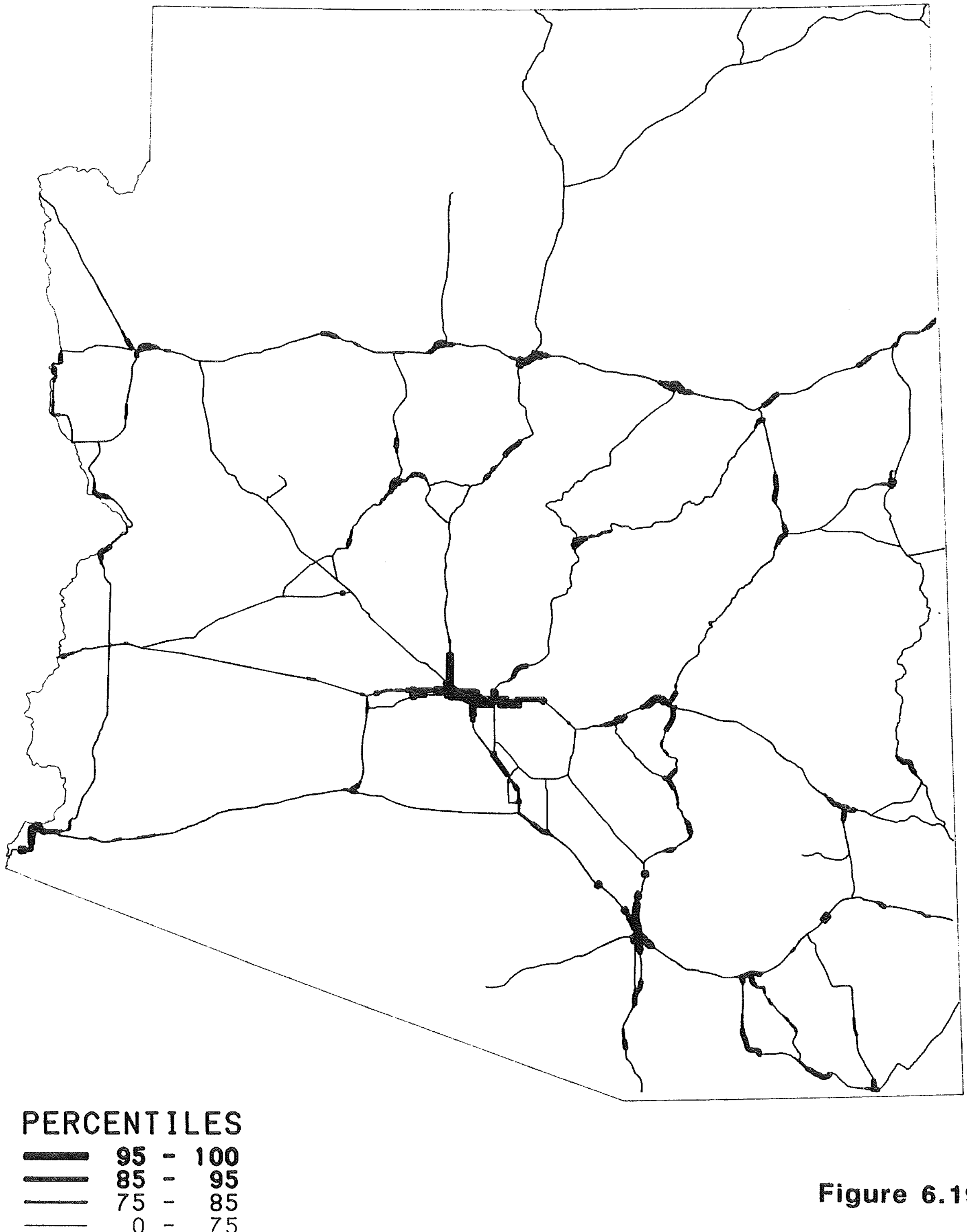


Figure 6.19

COMPOSITE VULNERABILITY

Risks of Transporting Hazardous Materials in Arizona

ATRC / Dames & Moore

7.0 IMPLICATIONS OF RISK ANALYSIS

This risk analysis has demonstrated a number of different techniques to assess risk of transporting hazardous materials. These include:

> the absolute hazard or the probability that an accident will take place that involves a hazardous material without regard to the consequences,
>
> assessing the consequences of hazardous materials incident by evaluating the number of people at risk, and
>
> assessing what impact mitigation of a hazardous materials accident through prompt emergency response will have on the number of people affected.

One must be very cautious about drawing conclusions from this analysis. The hazardous materials data are 5 to 6 years old and may not be characteristic of the current patterns of hazardous material transport. The actual estimated volumes of hazardous materials by route segment were not available. Therefore, the volumes of hazardous materials by class were estimated from figures in the 1986 report. However, these figures appear to represent only interstate movements and therefore are incomplete. In addition, only 1980 population data were available at the time of the analysis.

This analysis demonstrated the successful application of the geographic information system to address the risk analysis problem. Unlike the traditional risk analysis techniques, the GIS analysis allows for the consideration of numerous spatial considerations. Currently, GIS data are relatively limited. However, the 1990 census data will be available in a GIS format and can be easily utilized in future analysis. National highway files are also available.

The GIS analysis can be applied on a large-scale basis, such as a state-level analysis. It can also be used to conduct regional or local evaluations. The GIS risk analysis also has the capability to zoom in on specific areas of concern so that the information can be seen in greater detail.

The potential applications of the GIS analysis is very broad. Because of its flexibility, the extensive GIS databases that are being developed and the tremendous increase in computing power, it is likely that the GIS will be the primary risk analysis tool of the future. Potential applications and uses of the risk analysis might include:

- Highway construction and maintenance prioritization
- Routing of hazardous materials and waste
- Transportation mode alternative analysis
- Siting emergency response units
- Assessing and prioritizing training for emergency response units
- Evaluating risks to sensitive population centers
- Evaluating risks to sensitive ecological areas

There are also a number of private sector applications of the GIS risk analysis model:

- Minimum time and mileage routing
- Improved utilization of equipment and personnel
- Minimum population exposed routes
- Time of day risk analysis routing alternatives

Considerations of the risks to sensitive activities and land uses, such as hospitals, retirement homes and schools, may also be useful. These data could be easily integrated into the GIS database and evaluated.

8.0 RECOMMENDATIONS

As previously stated, the data available for this risk assessment were very limited. Complete and up to date data are necessary to draw meaningful route specific conclusions from the analysis. Therefore, we would recommend that a more comprehensive survey be conducted to assess the amount and routing of hazardous materials traveling throughout the state. Perhaps more permanent survey programs could be implemented at all ports of entry. Additionally, information concerning the volumes and routing of hazardous materials and wastes being transported on the rail systems throughout the state should be included in the risk analysis to obtain a complete understanding of the risks to the public.

The new 1990 census data should be utilized when it becomes available. A more detailed analysis should also take into consideration the population changes during a typical work day and on weekends. The population density in the urban areas shifts significantly during the work day. Shipments of particular hazardous materials might be controlled not only by the routes they can travel, but also by the time of day they may be transported. In addition, seasonal variations in traffic patterns should also be taken into consideration. Significant shifts in truck traffic from I-40 to I-10 during the winter months have been observed.

More detailed information regarding the staffing and response capabilities of the fire department units is essential if the risk analysis is to be used to optimize the locations and training of the emergency response units. Jurisdictional considerations should also be integrated into the model to more accurately reflect the actual areas that the emergency response units are authorized to serve.

Consideration of the risk to sensitive activities and land uses, such as hospitals, retirement homes and schools, may also be useful. These data could be easily integrated into the GIS database and evaluated.